to these additional functions also requires authentication. The AP 14 maintains a user list and the authentication means associated with each user. No application can gain access to location records or functions for which the application does not have proper authentication or access rights. In addition, the AP 14 supports full logging of all actions taken by each application in the event that problems arise or a later investigation into actions is required. For each command or function in the list below, the AP 14 preferably supports a protocol in which each action or the result of each is confirmed, as appropriate.

Edit Tasking List – This command permits external applications to add, remove, or edit entries in the Tasking List, including any fields and flags associated with each entry. This command can be supported on a single entry basis, or a batch entry basis where a list of entries is included in a single command. The latter is useful, for example, in a bulk application such as location sensitive billing whereby larger volumes of wireless transmitters are being supported by the external application, and it is desired to minimize protocol overhead. This command can add or delete applications for a particular entry in the Tasking List, however, this command cannot delete an entry entirely if the entry also contains other applications not associated with or authorized by the application issuing the command.

Set Location Interval – The Wireless Location System can be set to perform location processing at any interval for a particular wireless transmitter, on either control or voice channels. For example, certain applications may require the location of a wireless transmitter every few seconds when the transmitter is engaged on a voice channel. When the wireless transmitter make an initial transmission, the Wireless Location System initially triggers using a standard entry in the Tasking List. If one of the fields or flags in this entry specifies updated location on a set interval, then the Wireless Location System creates a dynamic task in the Tasking List that is triggered by a timer instead of an identity or other transmitted criteria. Each time the timer expires, which can range from 1 second to several hours, the Wireless Location System will automatically trigger to locate the wireless transmitter. The Wireless Location System uses its interface to the wireless communications system to query status of the wireless transmitter, including voice call parameters as described earlier.

If the wireless transmitter is engaged on a voice channel, then the Wireless Location System performs location processing. If the wireless transmitter is not engaged in any existing transmissions, the Wireless Location System will command the wireless communications system to make the wireless transmitter immediately transmit. When the dynamic task is set, the Wireless Location System also sets an expiration time at which the dynamic task ceases.

End-User Addition / Deletion – This command can be executed by an end-user of a wireless transmitter to place the identity of the wireless transmitter onto the Tasking List with location processing enabled, to remove the identity of the wireless transmitter from the Tasking List and therefore eliminate identity as a trigger, or to place the identity of the wireless transmitter onto the Tasking List with location processing disabled. When location processing has been disabled by the end-user, known as Prohibit Location Processing then no location processing will be performed for the wireless transmitter. The operator of the Wireless Location System can optionally select one of several actions by the Wireless Location System in response to a Prohibit Location Processing command by the end user: (i) the disabling action can override all other triggers in the Tasking List, including a trigger due to an emergency call such as "911", (ii) the disabling action can override any other trigger in the Tasking List, except a trigger due to an emergency call such as "911", (iii) the disabling action can be overridden by other select triggers in the Tasking List. In the first case, the end-user is granted complete control over the privacy of the transmissions by the wireless transmitter, as no location processing will be performed on that transmitter for any reason. In the second case, the end-user may still receive the benefits of location during an emergency, but at no other times. In an example of the third case, an employer who is the real owner of a particular wireless transmitter can override an end-user action by an employee who is using the wireless transmitter as part of the job but who may not desire to be located. The Wireless Location System may query the wireless communications system, as described above, to obtain the mapping of the identity contained in the wireless transmission to other identities.

The additions and deletions by the end-user are effected by dialed sequences of characters and digits and pressing the "SEND" or equivalent button on the wireless transmitter. These sequences may be optionally chosen and made known by the operator of the Wireless Location System. For example, one sequence may be "*55 SEND" to disable location processing. Other sequences are also possible. When the end-user can dialed this prescribed sequence, the wireless transmitter will transmit the sequence over one of the prescribed control channels of the wireless communications system. Since the Wireless Location System independently detects and demodulates all reverse control channel transmissions, the Wireless Location System can independently interpret the prescribed dialed sequence and make the appropriate feature updates to the Tasking List, as described above. When the Wireless Location System has completed the update to the Tasking List, the Wireless Location System commands the wireless communications system to send a confirmation to the end-user. As described earlier, this may take the form of an audible tone, recorded or synthesized voice, or a text message. This command is executed over the interface between the Wireless Location System and the wireless communications system.

Command Transmit – This command allows external applications to cause the Wireless Location System to send a command to the wireless communications system to make a particular wireless transmitter, or group of wireless transmitters, transmit. This command may contain a flag or field that the wireless transmitter(s) should transmit immediately or at a prescribed time. This command has the effort of locating the wireless transmitter(s) upon command, since the transmissions will be detected, demodulated, and triggered, causing location processing and the generation of a location record. This is useful in eliminating or reducing any delay in determining location such as waiting for the next registration time period for the wireless transmitter or waiting for an independent transmission to occur.

External Database Query and Update – The Wireless Location System includes means to access an external database, to query the said external database using the identity of the wireless transmitter or other parameters contained in the transmission or the trigger criteria, and to merge the data obtained from the external database with the data

generated by the Wireless Location System to create a new enhanced location record. The enhanced location record may then be forwarded to requesting applications. The external database may contain, for example, data elements such as customer information, medical information, subscribed features, application related information, customer account information, contact information, or sets of prescribed actions to take upon a location trigger event. The Wireless Location System may also cause updates to the external database, for example, to increment or decrement a billing counter associated with the provision of location services, or to update the external database with the latest location record associated with the particular wireless transmitter. The Wireless Location System contains means to performed the actions described herein on more than one external database. The list and sequence of external databases to access and the subsequent actions to take are contained in one of the fields contained in the trigger criteria in the Tasking List.

Random Anonymous Location Processing – The Wireless Location System includes means to perform large scale random anonymous location processing. This function is valuable to certain types of applications that require the gathering of a large volume of data about a population of wireless transmitters without consideration to the specific identities of the individual transmitters. Applications of this type include: RF Optimization, which enables wireless carriers to measure the performance of the wireless communications system by simultaneously determining location and other parameters of a transmission; Traffic Management, which enables government agencies and commercial concerns to monitor the flow of traffic on various highways using statistically significant samples of wireless transmitters travelling in vehicles; and Local Traffic Estimation, which enables commercial enterprises to estimate the flow of traffic around a particular area which may help determine the viability of particular businesses.

Applications requesting random anonymous location processing optionally receive location records from two sources: (i) a copy of location records generated for other applications, and (ii) location records which have been triggered randomly by the Wireless Location System without regard to any specific criteria. All of the location

records generated from either source are forwarded with all of the identity and trigger criteria information removed from the location records; however, the requesting application(s) can determine whether the record was generated from the fully random process or is a copy from another trigger criteria. The random location records are generated by a low priority task within the Wireless Location System that performs location processing on randomly selected transmissions whenever processing and communications resources are available and would otherwise be unused at a particular instant in time. The requesting application(s) can specify whether the random location processing is performed over the entire coverage area of a Wireless Location System, over specific geographic areas such as along prescribed highways, or by the coverage areas of specific cell sites. Thus, the requesting application(s) can direct the resources of the Wireless Location System to those area of greatest interest to each application. Depending on the randomness desired by the application(s), the Wireless Location System can adjust preferences for randomly selecting certain types of transmissions, for example, registration messages, origination messages, page response messages, or voice channel transmissions.

Anonymous Tracking of a Geographic Group – The Wireless Location System includes means to trigger location processing on a repetitive basis for anonymous groups of wireless transmitters within a prescribed geographic area. For example, a particular location application may desire to monitor the travel route of a wireless transmitter over a prescribed period of time, but without the Wireless Location System disclosing the particular identity of the wireless transmitter. The period of time may be many hours, days, or weeks. Using the means, the Wireless Location System: randomly selects a wireless transmitter that initiates a transmission in the geographic area of interest to the application; performs location processing on the transmission of interest; irreversibly translates and encrypts the identity of the wireless transmitter into a new coded identifier; creates a location record using only the new coded identifier as an identifying means; forwards the location record to the requesting location application(s); and creates a dynamic task in the Tasking List for the wireless transmitter, where the dynamic task has an associated expiration time. Subsequently, whenever the prescribed wireless transmitter initiates transmission, the Wireless

Location System shall trigger using the dynamic task, perform location processing on the transmission of interest, irreversibly translate and encrypt the identity of the wireless transmitter into the new coded identifier using the same means as prior such that the coded identifier is the same, create a location record using the coded identifier, and forward the location record to the requesting location application(s). The means described herein can be combined with other functions of the Wireless Location System to perform this type of monitoring use either control or voice channel transmissions. Further, the means described herein completely preserve the private identity of the wireless transmitter, yet enables another class of applications that can monitor the travel patterns of wireless transmitters. This class of applications can be of great value in determining the planning and design of new roads, alternate route planning, or the construction of commercial and retail space.

Location Record Grouping, Sorting, and Labeling – The Wireless Location System include means to post-process the location records for certain requesting applications to group, sort, or label the location records. For each interface supported by the Wireless Location System, the Wireless Location System stores a profile of the types of data for which the application is both authorized and requesting, and the types of filters or post-processing actions desired by the application. Many applications, such as the examples contained herein, do not require individual location records or the specific identities of individual transmitters. For example, an RF optimization application derives more value from a large data set of location records for a particular cell site or channel than it can from any individual location record. For another example, a traffic monitoring application requires only location records from transmitters that are on prescribed roads or highways, and additionally requires that these records be grouped by section of road or highway and by direction of travel. Other applications may request that the Wireless Location System forward location records that have been formatted to enhance visual display appeal by, for example, adjusting the location estimate of the transmitter so that the transmitter's location appears on an electronic map directly on a drawn road segment rather than adjacent to the road segment. Therefore, the Wireless Location System preferably "snaps" the location estimate to the nearest drawn road segment.

The Wireless Location System can filter and report location records to an application for wireless transmitters communicating only on a particular cell site, sector, RF channel, or group of RF channels. Before forwarding the record to the requesting application, the Wireless Location System first verifies that the appropriate fields in the record satisfy the requirements. Records not matching the requirements are not forwarded, and records matching the requirements are forwarded. Some filters are geographic and must be calculated by the Wireless Location System. For example, the Wireless Location System can process a location record to determine the closest road segment and direction of travel of the wireless transmitter on the road segment. The Wireless Location System can then forward only records to the application that are determined to be on a particular road segment, and can further enhance the location record by adding a field containing the determined road segment. In order to determine the closest road segment, the Wireless Location System is provided with a database of road segments of interest by the requesting application. This database is stored in a table where each road segment is stored with a latitude and longitude coordinate defining the end point of each segment. Each road segment can be modeled as a straight or curved line, and can be modeled to support one or two directions of travel. Then for each location record determined by the Wireless Location System, the Wireless Location System compares the latitude and longitude in the location record to each road segment stored in the database, and determines the shortest distance from a modeled line connecting the end points of the segment to the latitude and longitude of the location record. The shortest distance is a calculated imaginary line orthogonal to the line connecting the two end points of the stored road segment. When the closest road segment has been determined, the Wireless Location System can further determine the direction of travel on the road segment by comparing the direction of travel of the wireless transmitter reported by the location processing to the orientation of the road segment. The direction that produces the smallest error with respect to the orientation of the road segments is then reported by the Wireless Location System.

Network Operations Console (NOC) 16

The NOC 16 is a network management system that permits operators of the Wireless Location System easy access to the programming parameters of the Wireless Location System. For example, in some cities, the Wireless Location System may contain many hundreds or even thousands of SCS's 10. The NOC is the most effective way to manage a large Wireless Location System, using graphical user interface capabilities. The NOC will also receive real time alerts if certain functions within the Wireless Location System are not operating properly. These real time alerts can be used by the operator to take corrective action quickly and prevent a degradation of location service. Experience with trials of the Wireless Location System show that the ability of the system to maintain good location accuracy over time is directly related to the operator's ability to keep the system operating within its predetermined parameters.

Location Processing

The Wireless Location System is capable of performing location processing using two different methods known as central based processing and station based processing. Both techniques were first disclosed in Patent Number 5,327,144, and are further enhanced in this specification. Location processing depends in part on the ability to accurately determine certain phase characteristics of the signal as received at multiple antennas and at multiple SCS's 10. Therefore, it is an object of the Wireless Location System to identify and remove sources of phase error that impede the ability of the location processing to determine the phase characteristics of the received signal. One source of phase error is inside of the wireless transmitter itself, namely the oscillator (typically a crystal oscillator) and the phase lock loops that allow the phone to tune to specific channels for transmitting. Lower cost crystal oscillators will generally have higher phase noise. Some air interface specifications, such as IS-136 and IS-95A, have specifications covering the phase noise with which a wireless telephone can transmit. Other air interface specifications, such as IS-553A, do not closely specify phase noise. It is therefore an object of the present invention to automatically reduce and/or eliminate a wireless transmitter's phase noise as a source of phase error in location processing, in part by automatically selecting the use of central based processing or station based processing. The automatic selection will also

consider the efficiency with which the communications link between the SCS 10 and the TLP 12 is used, and the availability of DSP resources at each of the SCS 10 and TLP 12.

When using central based processing, the TDOA and FDOA determination and the multipath processing are performed in the TLP 12 along with the position and speed determination. This method is preferred when the wireless transmitter has a phase noise that is above a predetermined threshold. In these cases, central based processing is most effective in reducing or eliminating the phase noise of the wireless transmitter as a source of phase error because the TDOA estimate is performed using a digital representation of the actual RF transmission from two antennas, which may be at the same SCS 10 or different SCS's 10. In this method, those skilled in the art will recognize that the phase noise of the transmitter is a common mode noise in the TDOA processing, and therefore is self-canceling in the TDOA determination process. This method works best, for example, with many very low cost AMPS cellular telephones that have a high phase noise. The basic steps in central based processing include the steps recited below and represented in the flowchart of Figure 6:

a wireless transmitter initiates a transmission on either a control channel or a voice channel (step S50);

the transmission is received at multiple antennas and at multiple SCS's 10 in the Wireless Location System (step S51);

the transmission is converted into a digital format in the receiver connected to each SCS/antenna (step S52);

the digital data is stored in a memory in the receivers in each SCS 10 (step S53);

the transmission is demodulated (step S54);

the Wireless Location System determines whether to begin location processing for the transmission (step S55);

if triggered, the TLP 12 requests copies of the digital data from the memory in receivers at multiple SCS's 10 (step S56);

digital data is sent from multiple SCS's 10 to a selected TLP 12 (step S57);

the TLP 12 performs TDOA, FDOA, and multipath mitigation on the digital data from pairs of antennas (step S58);

the TLP 12 performs position and speed determination using the TDOA data, and then creates a location record and forwards the location record to the AP 14 (step S59).

The Wireless Location System uses a variable number of bits to represent the transmission when sending digital data from the SCS's 10 to the TLP 12. As discussed earlier, the SCS receiver digitizes wireless transmissions with a high resolution, or a high number of bits per digital sample in order to achieve a sufficient dynamic range. This is especially required when using wideband digital receivers, which may be simultaneously receiving signals near to the SCS 10A and far from the SCS 10B. For example, up to 14 bits may be required to represent a dynamic range of 84 dB. Location processing does not always require the high resolution per digital sample, however. Frequently, locations of sufficient accuracy are achievable by the Wireless Location System using a fewer number of bits per digital sample. Therefore, to minimize the implementation cost of the Wireless Location System by conserving bandwidth on the communication links between each SCS 10 and TLP 12, the Wireless Location System determines the fewest number of bits required to digitally represent a transmission while still maintaining a desired accuracy level. This determination is based, for example, on the particular air interface protocol used by the wireless transmitter, the SNR of the transmission, the degree to which the transmission has been perturbed by fading and/or multipath, and the current state of the processing and communication queues in each SCS 10. The number of bits sent from the SCS 10 to the TLP 12 are reduced in two ways: the number of bits per sample is minimized, and the shortest length, or fewest segments, of the transmission possible is used for location processing. The TLP 12 can use this minimal RF data to perform location processing and then compare the result with the desired accuracy level. This comparison is performed on the basis of a confidence interval calculation. If the location estimate does not fall within the desired accuracy limits, the TLP 12 will recursively request additional data from selected SCS's 10. The additional data may include an additional number of bits per digital sample and/or may include more segments of the transmission. This process of requesting additional data may continue recursively until the TLP 12 has achieved the prescribed location accuracy.

There are additional details to the basic steps described above. These details are described in prior Patent Numbers 5,327,144 and 5,608,410 in other parts of this specification. One enhancement to the processes described in earlier patents is the selection of a single reference SCS/antenna that is used for each baseline in the location processing. In prior art, baselines were determined using pairs of antenna sites around a ring. In the present Wireless Location System, the single reference SCS/antenna used is generally the highest SNR signal, although other criteria are also used as described below. The use of a high SNR reference aids central based location processing when the other SCS/antennas used in the location processing are very weak, such as at or below the noise floor (i.e. zero or negative signal to noise ratio). When station based location processing is used, the reference signal is a re-modulated signal, which is intentionally created to have a very high signal to noise ratio, further aiding location processing for very weak signals at other SCS/antennas. The actual selection of the reference SCS/antenna is described below.

The Wireless Location System mitigates multipath by first recursively estimating the components of multipath received in addition to the direct path component and then subtracting these components from the received signal. Thus the Wireless Location System models the received signal and compares the model to the actual received signal and attempts to minimize the difference between the two using a weighted least square difference. For each transmitted signal x(t) from a wireless transmitter, the received signal y(t) at each SCS/antenna is a complex combination of signals:

$$y(t) = \Sigma\, x(t - \tau_n) a_n\, e^{j\omega(t-\tau n)}, \text{ for all } n = 0 \text{ to } N;$$

where x(t) is the signal as transmitted by the wireless transmitter;

a_n and τ_n are the complex amplitude and delays of the multipath components;

N is the total number of multipath components in the received signal; and

a_0 and τ_0 are constants for the most direct path component.

The operator of the Wireless Location System empirically determines a set of constraints for each component of multipath that applies to the specific environment in which each Wireless Location System is operating. The purpose of the constraints is to limit the

amount of processing time that the Wireless Location System spends optimizing the results for each multipath mitigation calculation. For example, the Wireless Location System may be set to determine only four components of multipath: the first component may be assumed to have a time delay in the range τ_{1A} to τ_{1B}; the second component may be assumed to have a time delay in the range τ_{2A} to τ_{2B}; the third component may be assumed to have a time delay in the range τ_{3A} to τ_{3B}; and similar for the fourth component; however the fourth component is a single value that effectively represents a complex combination of many tens of individual (and somewhat diffuse) multipath components whose time delays exceed the range of the third component. For ease of processing, the Wireless Location System transforms the prior equation into the frequency domain, and then solves for the individual components such that a weighted least squares difference is minimized.

When using station based processing, the TDOA and FDOA determination and multipath mitigation are performed in the SCS's 10, while the position and speed determination are typically performed in the TLP 12. The main advantage of station based processing, as described in Patent Number 5,327,144, is reducing the amount of data that is sent on the communication link between each SCS 10 and TLP 12. However, there may be other advantages as well. One new objective of the present invention is increasing the effective signal processing gain during the TDOA processing. As pointed out earlier, central based processing has the advantage of eliminating or reducing phase error caused by the phase noise in the wireless transmitter. However, no previous disclosure has addressed how to eliminate or reduce the same phase noise error when using station based processing. The present invention reduces the phase error and increases the effective signal processing gain using the steps recited below and shown in Figure 6:

a wireless transmitter initiates a transmission on either a control channel or a voice channel (step S60);

the transmission is received at multiple antennas and at multiple SCS's 10 in the Wireless Location System (step S61);

the transmission is converted into a digital format in the receiver connected to each antenna (step S62);

the digital data is stored in a memory in the SCS 10 (step S63);

the transmission is demodulated (step S64);

the Wireless Location System determines whether to begin location processing for the transmission (step S65);

if triggered, a first SCS 10A demodulates the transmission and determines an appropriate phase correction interval (step S66);

for each such phase correction interval, the first SCS 10A calculates an appropriate phase correction and amplitude correction, and encodes this phase correction parameter and amplitude correction parameter along with the demodulated data (step S67);

the demodulated data and phase correction and amplitude correction parameters are sent from the first SCS 10A to a TLP 12 (step S68);

the TLP 12 determines the SCS's 10 and receiving antennas to use in the location processing (step S69);

the TLP 12 sends the demodulated data and phase correction and amplitude correction parameters to each second SCS 10B that will be used in the location processing (step S70);

the first SCS 10 and each second SCS 10B creates a first re-modulated signal based upon the demodulated data and the phase correction and amplitude correction parameters (step S71);

the first SCS 10A and each second SCS 10B performs TDOA, FDOA, and multipath mitigation using the digital data stored in memory in each SCS 10 and the first re-modulated signal (step S72);

the TDOA, FDOA, and multipath mitigation data are sent from the first SCS 10A and each second SCS 10B to the TLP 12 (step S73);

the TLP 12 performs position and speed determination using the TDOA data (step S74); and

the TLP 12 creates a location record, and forwards the location record to the AP 14 (step S75).

The advantages of determining phase correction and amplitude correction parameters are most obvious in the location of CDMA wireless transmitters based upon IS-95A. As is

well known, the reverse transmissions from an IS-95A transmitter are sent using non-coherent modulation. Most CDMA base stations only integrate over a single bit interval because of the non-coherent modulation. For a CDMA Access Channel, with a bit rate of 4800 bits per second, there are 256 chips sent per bit, which permits an integration gain of 24 dB. Using the technique described above, the TDOA processing in each SCS 10 may integrate, for example, over a full 160 millisecond burst (196,608 chips) to produce an integration gain of 53 dB. This additional processing gain enables the present invention to detect and locate CDMA transmissions using multiple SCS's 10, even if the base stations collocated with the SCS's 10 cannot detect the same CDMA transmission.

For a particular transmission, if either the phase correction parameters or the amplitude correction parameters are calculated to be zero, or are not needed, then these parameters are not sent in order to conserve on the number of bits transmitted on the communications link between each SCS 10 and TLP 12. In another embodiment of the invention, the Wireless Location System may use a fixed phase correction interval for a particular transmission or for all transmissions of a particular air interface protocol, or for all transmissions made by a particular type of wireless transmitter. This may, for example, be based upon empirical data gathered over some period of time by the Wireless Location System showing a reasonable consistency in the phase noise exhibited by various classes of transmitters. In these cases, the SCS 10 may save the processing step of determining the appropriate phase correction interval.

Those skilled in the art will recognize that there are many ways of measuring the phase noise of a wireless transmitter. In one embodiment, a pure, noiseless re-modulated copy of the signal received at the first SCS 10A may be digitally generated by DSP's in the SCS, then the received signal may be compared against the pure signal over each phase correction interval and the phase difference may be measured directly. In this embodiment, the phase correction parameter will be calculated as the negative of the phase difference over that phase correction interval. The number of bits required to represent the phase correction parameter will vary with the magnitude of the phase correction parameter, and the number of bits may vary for each phase correction interval. It has been

observed that some transmissions, for example, exhibit greater phase noise early in the transmission, and less phase noise in the middle of and later in the transmission.

Station based processing is most useful for wireless transmitters that have relatively low phase noise. Although not necessarily required by their respective air interface standards, wireless telephones that use the TDMA, CDMA, or GSM protocols will typically exhibit lower phase noise. As the phase noise of a wireless transmitter increases, the length of a phase correction interval may decrease and/or the number of bits required to represent the phase correction parameters increases. Station based processing is not effective when the number of bits required to represent the demodulated data plus the phase correction and amplitude parameters exceeds a predetermined proportion of the number of bits required to perform central based processing. It is therefore an object of the present invention to automatically determine for each transmission for which a location is desired whether to process the location using central based processing or station based processing. The steps in making this determination are recited below and shown in Figure 7:

a wireless transmitter initiates a transmission on either a control channel or a voice channel (step S80);

the transmission is received at a first SCS 10A (step S81);

the transmission is converted into a digital format in the receiver connected to each antenna (step S82);

the Wireless Location System determines whether to begin location processing for the transmission (step S83);

if triggered, a first SCS 10A demodulates the transmission and estimates an appropriate phase correction interval and the number of bits required to encode the phase correction and amplitude correction parameters (step S84);

the first SCS 10A then estimates the number of bits required for central based processing;

based upon the number of bits required for each respective method, the SCS 10 or the TLP 12 determine whether to use central based processing or station based processing to perform the location processing for this transmission (step S85).

In another embodiment of the invention, the Wireless Location System may always use central based processing or station based processing for all transmissions of a particular air interface protocol, or for all transmissions made by a particular kind of wireless transmitter. This may, for example, be based upon empirical data gathered over some period of time by the Wireless Location System showing a reasonable consistency in the phase noise exhibited by various classes of transmitters. In these cases, the SCS 10 and/or the TLP 12 may be saved the processing step of determining the appropriate processing method.

A further enhancement of the present invention, used for both central based processing and station based processing, is the use of threshold criteria for including baselines in the final determination of location and velocity of the wireless transmitter. For each baseline, the Wireless Location System calculates a number of parameters that include: the SCS/antenna port used with the reference SCS/antenna in calculating the baseline, the peak, average, and variance in the power of the transmission as received at the SCS/antenna port used in the baseline and over the interval used for location processing, the correlation value from the cross-spectra correlation between the SCS/antenna used in the baseline and the reference SCS/antenna, the delay value for the baseline, the multipath mitigation parameters, the residual values remaining after the multipath mitigation calculations, the contribution of the SCS/antenna to the weighted GDOP in the final location solution, and a measure of the quality of fit of the baseline if included in the final location solution. Each baseline is included in the final location solution is each meets or exceeds the threshold criteria for each of the parameters described herein. A baseline may be excluded from the location solution if it fails to meet one or more of the threshold criteria. Therefore, it is frequently possible that the number of SCS/antennas actually used in the final location solution is less than the total number considered.

Previous Patent Numbers 5,327,144 and 5,608,410 disclosed a method by which the location processing minimized the least square difference (LSD) value of the following equation:

$$LSD = [Q_{12}(Delay\_T_{12}-Delay\_O_{12})^2 + Q_{13}(Delay\_T_{13}-Delay\_O_{13})^2 + \ldots + Q_{xy}(Delay\_T_{xy}-Delay\_O_{xy})^2$$

In the present implementation, this equation has been rearranged to the following form in order to make the location processing code more efficient:

$$LSD = \Sigma\,(TDOA_{0i} - \tau_i + \tau_0)^2 w_i^2\text{; over all } i=1 \text{ to } N-1$$

where N = number of SCS/antennas used in the location processing;
$TDOA_{0i}$ = the TDOA to the i^{th} site from reference site 0;
τ_i = the theoretical line of sight propagation time from the wireless transmitter to the i^{th} site;
τ_0 = the theoretical line of sight propagation time from the transmitter to the reference; and
w_i = the weight, or quality factor, applied to the i^{th} baseline.

In the present implementation, the Wireless Location System also uses another alternate form of the equation that can aid in determining location solutions when the reference signal is not very strong or when it is likely that a bias would exist in the location solution using the prior form of the equation:

$$LSD' = \Sigma\,(TDOA_{0i} - \tau_i)^2 w_i^2 - b^2\,\Sigma\,w_i^2\text{; over all } i=0 \text{ to } N-1$$

Where N = number of SCS/antennas used in the location processing;
$TDOA_{0i}$ = the TDOA to the i^{th} site from reference site 0;
$TDOA_{00}$ = is assumed to be zero;
τ_i = the theoretical line of sight propagation time from the wireless transmitter to the i^{th} site;
b = a bias that is separately calculated for each theoretical point that minimizes LSD' at that theoretical point; and
w_i = the weight, or quality factor, applied to the i^{th} baseline.

The LSD' form of the equation offers an easier means of removing a bias in location solutions at the reference site by making w_0 equal to the maximum value of the other weights or basing w_0 on the relative signal strength at the reference site. Note that if w_0 is much larger than the other weights, then b is approximately equal to τ_0. In general, the weights, or quality factors are based on similar criteria to that discussed above for the threshold criteria in including baselines. That is, the results of the criteria calculations are used for weights and when the criteria falls below threshold the weight is then set to zero and is effectively not included in the determination of the final location solution.

Antenna Selection Process for Location Processing

Previous inventions and disclosures, such as those listed above, have described techniques in which a first, second, or possibly third antenna site, cell site, or base station are required to determine location. Patent number 5,608,410 further discloses a Dynamic Selection Subsystem (DSS) that is responsible for determining which data frames from which antenna site locations will be used to calculate the location of a responsive transmitter. In the DSS, if data frames are received from more than a threshold number of sites, the DSS determines which are candidates for retention or exclusion, and then dynamically organizes data frames for location processing. The DSS prefers to use more than the minimum number of antenna sites so that the solution is over-determined. Additionally, the DSS assures that all transmissions used in the location processing were received from the same transmitter and from the same transmission.

The preferred embodiments of the prior inventions had several limitations, however. First, either only one antenna per antenna site (or cell site) is used, or the data from two or four diversity antennas were first combined at the antenna site (or cell site) prior to transmission to the central site. Additionally, all antenna sites that received the transmission sent data frames to the central site, even if the DSS later discarded the data frames. Thus, some communications bandwidth may have been wasted sending data that was not used.

The present inventors have determined that while a minimum of two or three sites are required in order determine location, the actual selection of antennas and SCS's 10 to use

in location processing can have a significant effect on the results of the location processing. In addition, it is advantageous to include the means to use more than one antenna at each SCS 10 in the location processing. The reason for using data from multiple antennas at a cell site independently in the location processing is that the signal received at each antenna is uniquely affected by multipath, fading, and other disturbances. It is well known in the field that when two antennas are separated in distance by more than one wavelength, then each antenna will receive the signal on an independent path. Therefore, there is frequently additional and unique information to be gained about the location of the wireless transmitter by using multiple antennas, and the ability of the Wireless Location System to mitigate multipath is enhanced accordingly.

It is therefore an object of the present invention to provide an improved method for using the signals received from more than one antenna at an SCS 10 in the location processing. It is a further object to provide a method to improve the dynamic process used to select the cooperating antennas and SCS's 10 used in the location processing. The first object is achieved by providing means within the SCS 10 to select and use any segment of data collected from any number of antennas at an SCS in the location processing. As described earlier, each antenna at a cell site is connected to a receiver internal to the SCS 10. Each receiver converts signals received from the antenna into a digital form, and then stores the digitized signals temporarily in a memory in the receiver. The TLP 12 has been provided with means to direct any SCS 10 to retrieve segments of data from the temporary memory of any receiver, and to provide the data for use in location processing. The second object is achieved by providing means within the Wireless Location System to monitor a large number of antennas for reception of the transmission that the Wireless Location System desires to locate, and then selecting a smaller set of antennas for use in location processing based upon a predetermined set of parameters. One example of this selection process is represented by the flowchart of Figure 8:

a wireless transmitter initiates a transmission on either a control channel or a voice channel (step S90);

the transmission is received at multiple antennas and at multiple SCS's 10 in the Wireless Location System (step S91);

the transmission is converted into a digital format in the receiver connected to each antenna (step S92);

the digital data is stored in a memory in each SCS 10 (step S93);

the transmission is demodulated at at least one SCS 10A and the channel number on which the transmission occurred and the cell site and sector serving the wireless transmitter is determined (step S94);

based upon the serving cell site and sector, one SCS 10A is designated as the 'primary' SCS 10 for processing that transmission (step S95);

the primary SCS 10A determines a timestamp associated with the demodulated data (step S96);

the Wireless Location System determines whether to begin location processing for the transmission (step S97);

if location processing is triggered, the Wireless Location System determines a candidate list of SCS's 10 and antennas to use in the location processing (step S98);

each candidate SCS/antenna measures and reports several parameters in the channel number of the transmission and at the time of the timestamp determined by the primary SCS 10A (step S99);

the Wireless Location System orders the candidate SCS/antennas using specified criteria and selects a reference SCS/antenna and a processing list of SCS/antennas to use in the location processing (step S100); and

the Wireless Location System proceeds with location processing as described earlier, using data from the processing list of SCS/antennas (step S101).

Selecting Primary SCS/Antenna

The process for choosing the 'primary' SCS/antenna is critical, because the candidate list of SCS's 10 and antennas 10-1 is determined in part based upon the designation of the primary SCS/antenna. When a wireless transmitter makes a transmission on a particular RF channel, the transmission frequently can propagate many miles before the signal attenuates below a level at which it can be demodulated. Therefore, there are frequently many SCS/antennas capable of demodulating the signal. This especially occurs is urban and suburban areas where the frequency re-use pattern of many wireless communications systems can be quite dense. For example, because of the high usage rate of wireless and

the dense cell site spacing, the present inventors have tested wireless communications systems in which the same RF control channel and digital color code were used on cell sites spaced about one mile apart. Because the Wireless Location System is independently demodulating these transmissions, the Wireless Location System frequently can demodulate the same transmission at two, three, or more separate SCS/antennas. The Wireless Location System detects that the same transmission has been demodulated multiple times at multiple SCS/antennas when the Wireless Location System receives multiple demodulated data frames sent from different SCS/antennas, each with a number of bit errors below a predetermined bit error threshold, and with the demodulated data matching within an acceptable limit of bit errors, and all occurring within a predetermined interval of time.

When the Wireless Location System detects demodulated data from multiple SCS/antennas, it examines the following parameters to determine which SCS/antenna shall be designated the primary SCS: average SNR over the transmission interval used for location processing, the variance in the SNR over the same interval, correlation of the beginning of the received transmission against a pure pre-cursor (i.e. for AMPS, the dotting and Barker code), the number of bit errors in the demodulated data, and the magnitude and rate of change of the SNR from just before the on-set of the transmission to the on-set of the transmission, as well as other similar parameters. The average SNR is typically determined at each SCS/antenna either over the entire length of the transmission to be used for location processing, or over a shorter interval. The average SNR over the shorter interval can be determined by performing a correlation with the dotting sequence and/or Barker code and/or sync word, depending on the particular air interface protocol, and over a short range of time before, during, and after the timestamp reported by each SCS 10. The time range may typically be +/-200 microseconds centered at the timestamp, for example. The Wireless Location System will generally order the SCS/antennas using the following criteria, each of which may be weighted (multiplied by an appropriate factor) when combining the criteria to determine the final decision: SCS/antennas with a lower number of bit errors are preferred to SCS/antennas with a higher number of bit errors, average SNR for a given SCS/antenna must be greater than a predetermined threshold to be designated as the primary; SCS/antennas with higher average SNR are

preferred over those with lower average SNR; SCS/antennas with lower SNR variance are preferred to those with higher SNR variance; and SCS/antennas with a faster SNR rate of change at the on-set of the transmission are preferred to those with a slower rate of change. The weighting applied to each of these criteria may be adjusted by the operator of the Wireless Location System to suit the particular design of each system.

The candidate list of SCS's 10 and antennas 10-1 are selected using a predetermined set of criteria based, for example, upon knowledge of the types of cell sites, types of antennas at the cell sites, geometry of the antennas, and a weighting factor that weights certain antennas more than other antennas. The weighting factor takes into account knowledge of the terrain in which the Wireless Location System is operating, past empirical data on the contribution of each antenna has made to good location estimates, and other factors that may be specific to each different WLS installation. In one embodiment, for example, the Wireless Location System may select the candidate list to include all SCS's 10 up to a maximum number of sites (max_number_of_sites) that are closer than a predefined maximum radius from the primary site (max_radius_from_primary). For example, in an urban or suburban environment, where there may be a large number of cell sites, the max_number_of_sites may be limited to nineteen. Nineteen sites would include the primary, the first ring of six sites surrounding the primary (assuming a classic hexagonal distribution of cell sites), and the next ring of twelve sites surrounding the first ring. This is depicted in Figure 9. In another embodiment, in a suburban or rural environment, max_radius_from_primary may be set to 40 miles to ensure that the widest possible set of candidate SCS/antennas is available. The Wireless Location System is provided with means to limit the total number of candidate SCS's 10 to a maximum number (max_number_candidates), although each candidate SCS may be permitted to choose the best port from among its available antennas. This limits the maximum time spent by the Wireless Location System processing a particular location. Max_number_candidates may be set to thirty-two, for example, which means that in a typical three sector wireless communications system with diversity, up to 32*6 = 192 total antennas could be considered for location processing for a particular transmission. In order to limit the time spent processing a particular location, the Wireless Location System is provided with means to limit the number of antennas used in the location processing to

max_number_antennas_processed. Max_number_antennas_processed is generally less than max_number_candidates, and is typically set to sixteen.

While the Wireless Location System is provided with the ability to dynamically determine the candidate list of SCS's 10 and antennas based upon the predetermined set of criteria described above, the Wireless Location System can also store a fixed candidate list in a table. Thus, for each cell site and sector in the wireless communications system, the Wireless Location System has a separate table that defines the candidate list of SCS's 10 and antennas 10-1 to use whenever a wireless transmitter initiates a transmission in that cell site and sector. Rather than dynamically choose the candidate SCS/antennas each time a location request is triggered, the Wireless Location System reads the candidate list directly from the table when location processing is initiated.

In general, a large number of candidate SCS's 10 is chosen to provide the Wireless Location System with sufficient opportunity and ability to measure and mitigate multipath. On any given transmission, any one or more particular antennas at one or more SCS's 10 may receive signals that have been affected to varying degrees by multipath. Therefore, it is advantageous to provide this means within the Wireless Location System to dynamically select a set of antennas which may have received less multipath than other antennas. The Wireless Location System uses various techniques to mitigate as much multipath as possible from any received signal; however it is frequently prudent to choose a set of antennas that contain the least amount of multipath.

Choosing Reference and Cooperating SCS/Antennas

In choosing the set of SCS/antennas to use in location processing, the Wireless Location System orders the candidate SCS/antennas using several criteria, including for example: average SNR over the transmission interval used for location processing, the variance in the SNR over the same interval, correlation of the beginning of the received transmission against a pure pre-cursor (i.e. for AMPS, the dotting and Barker code) and/or demodulated data from the primary SCS/antenna, the time of the on-set of the transmission relative to the on-set reported at the SCS/antenna at which the transmission was demodulated, and the magnitude and rate of change of the SNR from just before the on-set of the

transmission to the on-set of the transmission, as well as other similar parameters. The average SNR is typically determined at each SCS, and for each antenna in the candidate list either over the entire length of the transmission to be used for location processing, or over a shorter interval. The average SNR over the shorter interval can be determined by performing a correlation with the dotting sequence and/or Barker code and/or sync word, depending on the particular air interface protocol, and over a short range of time before, during, and after the timestamp reported by the primary SCS 10. The time range may typically be +/- 200 microseconds centered at the timestamp, for example. The Wireless Location System will generally order the candidate SCS/antennas using the following criteria, each of which may be weighted when combining the criteria to determine the final decision: average SNR for a given SCS/antenna must be greater than a predetermined threshold to be used in location processing; SCS/antennas with higher average SNR are preferred over those with lower average SNR; SCS/antennas with lower SNR variance are preferred to those with higher SNR variance; SCS/antennas with an on-set closer to the on-set reported by the demodulating SCS/antenna are preferred to those with an on-set more distant in time; SCS/antennas with a faster SNR rate of change are preferred to those with a slower rate of change; SCS/antennas with lower incremental weighted GDOP are preferred over those with higher incremental weighted GDOP, where the weighting is based upon estimated path loss from the primary SCS. The weighting applied to each of these preferences may be adjusted by the operator of the Wireless Location System to suit the particular design of each system. The number of different SCS's 10 used in the location processing is maximized up to a predetermined limit; the number of antennas used at each SCS 10 in limited to a predetermined limit; and the total number of SCS/antennas used is limited to max_number_antennas_processed. The SCS/antenna with the highest ranking using the above described process is designated as the reference SCS/antenna for location processing.

Best Port Selection Within an SCS 10

Frequently, the SCS/antennas in the candidate list or in the list to use in location processing will include only one or two antennas at a particular SCS 10. In these cases, the Wireless Location System may permit the SCS 10 to choose the "best port" from all or some of the antennas at the particular SCS 10. For example, if the Wireless Location

System chooses to use only one antenna at a first SCS 10, then the first SCS 10 may select the best antenna port from the typical six antenna ports that are connected to that SCS 10, or it may choose the best antenna port from among the two antenna ports of just one sector of the cell site. The best antenna port is chosen by using the same process and comparing the same parameters as described above for choosing the set of SCS/antennas to use in location processing, except that all of the antennas being considered for best port are all in the same SCS 10. In comparing antennas for best port, the SCS 10 may also optionally divide the received signal into segments, and then measure the SNR separately in each segment of the received signal. Then, the SCS 10 can optionally choose the best antenna port with highest SNR either by (i) using the antenna port with the most segments with the highest SNR, (ii) averaging the SNR in all segments and using the antenna port with the highest average SNR, or (iii) using the antenna port with the highest SNR in any one segment.

Detection and Recovery From Collisions

Because the Wireless Location System will use data from many SCS/antenna ports in location processing, there is a chance that the received signal at one or more particular SCS/antenna ports contains energy that is co-channel interference from another wireless transmitter (i.e. a partial or full collision between two separate wireless transmissions has occurred). There is also a reasonable probability that the co-channel interference has a much higher SNR than the signal from the target wireless transmitter, and if not detected by the Wireless Location System, the co-channel interference may cause an incorrect choice of best antenna port at an SCS 10, reference SCS/antenna, candidate SCS/antenna, or SCS/antenna to be used in location processing. The co-channel interference may also cause poor TDOA and FDOA results, leading to a failed or poor location estimate. The probability of collision increases with the density of cell sites in the host wireless communications system, especially in dense suburban or rural environments where the frequencies are re-used often and wireless usage by subscribers is high.

Therefore, the Wireless Location System includes means to detect and recover from the types of collisions described above. For example, in the process of selecting a best port, reference SCS/antenna, or candidate SCS/antenna, the Wireless Location System

determines the average SNR of the received signal and the variance of the SNR over the interval of the transmission; when the variance of the SNR is above a predetermined threshold, the Wireless Location System assigns a probability that a collision has occurred. If the signal received at an SCS/antenna has increased or decreased its SNR in a single step, and by an amount greater than a predetermined threshold, the Wireless Location System assigns a probability that a collision has occurred. Further, if the average SNR of the signal received at a remote SCS is greater than the average SNR that would be predicted by a propagation model, given the cell site at which the wireless transmitter initiated its transmission and the known transmit power levels and antenna patterns of the transmitter and receive antennas, the Wireless Location System assigns a probability that a collision has occurred. If the probability that a collision has occurred is above a predetermined threshold, then the Wireless Location System performs the further processing described below to verify whether and to what extent a collision may have impaired the received signal at an SCS/antenna. The advantage of assigning probabilities is to reduce or eliminate extra processing for the majority of transmissions for which collisions have not occurred. It should be noted that the threshold levels, assigned probabilities, and other details of the collision detection and recovery processes described herein are configurable, i.e., selected based on the particular application, environment, system variables, etc., that would affect their selection.

For received transmissions at an SCS/antenna for which the probability of a collision is above the predetermined threshold and before using RF data from a particular antenna port in a reference SCS/antenna determination, best port determination or in location processing, the Wireless Location System preferably verifies that the RF data from each antenna port is from the correct wireless transmitter. This is determined, for example, by demodulating segments of the received signal to verify, for example, that the MIN, MSID, or other identifying information is correct or that the dialed digits or other message characteristics match those received by the SCS/antenna that initially demodulated the transmission. The Wireless Location System may also correlate a short segment of the received signal at an antenna port with the signal received at the primary SCS 10 to verify that the correlation result is above a predetermined threshold. If the Wireless Location System detects that the variance in the SNR over the entire length of the transmission is

above a pre-determined threshold, the Wireless Location System may divide the transmission into segments and test each segment as described herein to determine whether the energy in that segment is primarily from the signal from the wireless transmitter for which location processing has been selected or from an interfering transmitter.

The Wireless Location System may choose to use the RF data from a particular SCS/antenna in location processing even if the Wireless Location System has detected that a partial collision has occurred at that SCS/antenna. In these cases, the SCS 10 uses the means described above to identify that portion of the received transmission which represents a signal from the wireless transmitter for which location processing has been selected, and that portion of the received transmission which contains co-channel interference. The Wireless Location System may command the SCS 10 to send or use only selected segments of the received transmission that do not contain the co-channel interference. When determining the TDOA and FDOA for a baseline using only selected segments from an SCS/antenna, the Wireless Location System uses only the corresponding segments of the transmission as received at the reference SCS/antenna. The Wireless Location System may continue to use all segments for baselines in which no collisions were detected. In many cases, the Wireless Location System is able to complete location processing and achieve an acceptable location error using only a portion of the transmission. This inventive ability to select the appropriate subset of the received transmission and perform location processing on a segment by segment basis enables the Wireless Location System to successfully complete location processing in cases that might have failed using previous techniques.

Multiple Pass Location Processing

Certain applications may require a very fast estimate of the general location of a wireless transmitter, followed by a more accurate estimate of the location that can be sent subsequently. This can be valuable, for example, for E9-1-1 systems that handle wireless calls and must make a call routing decision very quickly, but can wait a little longer for a more exact location to be displayed upon the E9-1-1 call-taker's electronic map terminal.

The Wireless Location System supports these applications with an inventive multiple pass location processing mode.

In many cases, location accuracy is enhanced by using longer segments of the transmission and increasing the processing gain through longer integration intervals. But longer segments of the transmission require longer processing periods in the SCS 10 and TLP 12, as well as longer time periods for transmitting the RF data across the communications interface from the SCS 10 to the TLP 12. Therefore, the Wireless Location System includes means to identify those transmissions that require a fast but rough estimate of the location followed by more complete location processing that produces a better location estimate. The Signal of Interest Table includes a flag for each Signal of Interest that requires a multiple pass location approach. This flag specifies the maximum amount of time permitted by the requesting location application for the first estimate to be sent, as well as the maximum amount of time permitted by the requesting location application for the final location estimate to be sent. The Wireless Location System performs the rough location estimate by selecting a subset of the transmission for which to perform location processing. The Wireless Location System may choose, for example, the segment that was identified at the primary SCS/antenna with the highest average SNR. After the rough location estimate has been determined, using the methods described earlier, but with only a subset of the transmission, the TLP 12 forwards the location estimate to the AP 14, which then forwards the rough estimate to the requesting application with a flag indicating that the estimate is only rough. The Wireless Location System then performs its standard location processing using all of the aforementioned methods, and forwards this location estimate with a flag indicating the final status of this location estimate. The Wireless Location System may perform the rough location estimate and the final location estimate sequentially on the same DSP in a TLP 12, or may perform the location processing in parallel on different DSP's. Parallel processing may be necessary to meet the maximum time requirements of the requesting location applications. The Wireless Location System supports different maximum time requirements from different location applications for the same wireless transmission.

Very Short Baseline TDOA

The Wireless Location System is designed to operate in urban, suburban, and rural areas. In rural areas, when there are not sufficient cell sites available from a single wireless carrier, the Wireless Location System can be deployed with SCS's 10 located at the cell sites of other wireless carriers or at other types of towers, including AM or FM radio station, paging, and two-way wireless towers. In these cases, rather than sharing the existing antennas of the wireless carrier, the Wireless Location System may require the installation of appropriate antennas, filters, and low noise amplifiers to match the frequency band of the wireless transmitters of interest to be located. For example, an AM radio station tower may require the addition of 800 MHz antennas to locate cellular band transmitters. There may be cases, however, where no additional towers of any type are available at reasonable cost and the Wireless Location System must be deployed on just a few towers of the wireless carrier. In these cases, the Wireless Location System supports an antenna mode known as very short baseline TDOA. This antenna mode becomes active when additional antennas are installed on a single cell site tower, whereby the antennas are placed at a distance of less than one wavelength apart. This may require the addition of just one antenna per cell site sector such that the Wireless Location System uses one existing receive antenna in a sector and one additional antenna that has been placed next to the existing receive antenna. Typically, the two antennas in the sector are oriented such that the primary axes, or line of direction, of the main beams are parallel and the spacing between the two antenna elements is known with precision. In addition, the two RF paths from the antenna elements to the receivers in the SCS 10 are calibrated.

In its normal mode, the Wireless Location System determines the TDOA and FDOA for pairs of antenna that are separated by many wavelengths. For a TDOA on a baseline using antennas from two difference cell sites, the pairs of antennas are separated by thousands of wavelengths. For a TDOA on a baseline using antennas at the same cell site, the pairs of antennas are separated by tens of wavelengths. In either case, the TDOA determination effectively results in a hyperbolic line bisecting the baseline and passing through the location of the wireless transmitter. When antennas are separated by multiple wavelengths, the received signal has taken independent paths from the wireless transmitter to each antenna, including experiencing different multipath and Doppler shifts. However, when

two antennas are closer than one wavelength, the two received signals have taken essentially the same path and experienced the same fading, multipath, and Doppler shift. Therefore, the TDOA and FDOA processing of the Wireless Location System typically produces a Doppler shift of zero (or near-zero) hertz, and a time difference on the order of zero to one nanosecond. A time difference that short is equivalent to an unambiguous phase difference between the signals received at the two antennas on the very short baseline. For example, at 834 MHz, the wavelength of an AMPS reverse control channel transmission is about 1.18 feet. A time difference of 0.1 nanoseconds is equivalent to a received phase difference of about 30 degrees. In this case, the TDOA measurement produces a hyperbola that is essentially a straight line, still passing through the location of the wireless transmitter, and in a direction that is rotated 30 degrees from the direction of the parallel lines formed by the two antennas on the very short baseline. When the results of this very short baseline TDOA at the single cell site are combined with a TDOA measurement on a baseline between two cell sites, the Wireless Location System can determine a location estimate using only two cell sites.

Bandwidth Monitoring Method For Improving Location Accuracy

AMPS cellular transmitters presently comprise the large majority of the wireless transmitters used in the U.S. and AMPS reverse voice channel transmissions are generally FM signals modulated by both voice and a supervisory audio tone (SAT). The voice modulation is standard FM, and is directly proportional to the speaking voice of the person using the wireless transmitter. In a typical conversation, each person speaks less that 35% of the time, which means that most of the time the reverse voice channel is not being modulated due to voice. With or without voice, the reverse channel is continuously modulated by SAT, which is used by the wireless communications system to monitor channel status. The SAT modulation rate is only about 6 KHz. The voice channels support in-band messages that are used for hand-off control and for other reasons, such as for establishing a 3-way call, for answering a second incoming call while already on a first call, or for responding to an 'audit' message from the wireless communications system. All of these messages, though carried on the voice channel, have characteristics similar to the control channel messages. These messages are transmitted infrequently, and location

systems have ignored these messages and focused on the more prevalent SAT transmissions as the signal of interest.

In view of the above-described difficulties presented by the limited bandwidth of the FM voice and SAT reverse voice channel signals, an object of the present invention is to provide an improved method by which reverse voice channel (RVC) signals may be utilized to locate a wireless transmitter, particularly in an emergency situation. Another object of the invention is to provide a location method that allows the location system to avoid making location estimates using RVC signals in situations in which it is likely that the measurement will not meet prescribed accuracy and reliability requirements. This saves system resources and improves the location system's overall efficiency. The improved method is based upon two techniques. Figure 10A is a flowchart of a first method in accordance with the present invention for measuring location using reverse voice channel signals. The method comprises the following steps:

(i) It is first assumed that a user with a wireless transmitter wishes to be located, or wishes to have his location updated or improved upon. This may be the case, for example, if the wireless user has dialed "911" and is seeking emergency assistance. It is therefore also assumed that the user is coherent and in communication with a centrally located dispatcher.

(ii) When the dispatcher desires a location update for a particular wireless transmitter, the dispatcher sends a location update command with the identity of the wireless transmitter to the Wireless Location System over an application interface.

(iii) The Wireless Location System responds to the dispatcher with a confirmation that the Wireless Location System has queried the wireless communications system and has obtained the voice channel assignment for the wireless transmitter.

(iv) The dispatcher instructs the wireless user to dial a 9 or more digit number and then the "SEND" button. This sequence may be something like "123456789" or "911911911". Two functions happen to the reverse voice channel when the wireless user dial a sequence of at least 9 digits and then the "SEND" button. First, especially for an AMPS cellular voice channel, the dialing of digits causes the sending of dual tone multi-frequency (DTMF) tones over the voice channel. The

modulation index of DTMF tones is very high and during the sending of each digit in the DTMF sequence will typically push the bandwidth of the transmitted signal beyond +/- 10 KHz. The second function occurs at the pressing of the "SEND" button. Whether or not the wireless user subscribes to 3-way calling or other special features, the wireless transmitter will send a message over the voice using a "blank and burst" mode where the transmitter briefly stops sending the FM voice and SAT, and instead sends a bursty message modulated in the same manner as the control channel (10 Kbits Manchester). If the wireless user dials less than 9 digits, the message will be comprised of approximately 544 bits. If the wireless user dials 9 or more digits, the message is comprised of approximately 987 bits.

(v) After notification by the dispatcher, the Wireless Location System monitors the bandwidth of the transmitted signal in the voice channel. As discussed earlier, when only the SAT is being transmitted, and even if voice and SAT are being transmitted, there may not be sufficient bandwidth in the transmitted signal to calculate a high quality location estimate. Therefore, the Wireless Location System conserves location processing resources and waits until the transmitted signal exceeds a predetermined bandwidth. This may be, for example, set somewhere in the range of 8 KHz to 12 KHz. When the DTMF dialed digits are sent or when the bursty message is sent, the bandwidth would typically exceed the predetermined bandwidth. In fact, if the wireless transmitter does transmit the DTMF tones during dialing, the bandwidth would be expected to exceed the predetermined bandwidth multiple times. This would provide multiple opportunities to perform a location estimate. If the DTMF tones are not sent during dialing, the bursty message is still sent at the time of pressing "SEND", and the bandwidth would typically exceed the predetermined threshold.

(vi) Only when the transmitted bandwidth of the signal exceeds the predetermined bandwidth, the Wireless Location System initiates location processing.

Figure 10B is a flowchart of another method in accordance with the present invention for measuring location using reverse voice channel signals. The method comprises the following steps:

(i) It is first assumed that a user with a wireless transmitter wishes to be located, or wishes to have their location updated or improved upon. This may be the case, for example, if the wireless user has dialed "911" and is seeking emergency assistance. It is assumed that the user may not wish to dial digits or may not be able to dial any digits in accordance with the previous method.

(ii) When the dispatcher desires a location update for a particular wireless transmitter user, the dispatcher sends a location update command to the Wireless Location System over an application interface with the identity of the wireless transmitter.

(iii) The Wireless Location System responds to the dispatcher with a confirmation.

(iv) The Wireless Location System commands the wireless communications system to make the wireless transmitter transmit by sending an "audit" or similar message to the wireless transmitter. The audit message is a mechanism by which the wireless communications system can obtain a response from the wireless transmitter without requiring an action by the end-user and without causing the wireless transmitter to ring or otherwise alert. The receipt of an audit message causes the wireless transmitter to respond with an "audit response" message on the voice channel.

(v) After notification by the dispatcher, the Wireless Location System monitors the bandwidth of the transmitted signal in the voice channel. As discussed earlier, when only the SAT is being transmitted, and even if voice and SAT are being transmitted, there may not be sufficient bandwidth in the transmitted signal to calculate a high quality location estimate. Therefore, the radio location conserves location processing resources and waits until the transmitted signal exceeds a predetermined bandwidth. This may be, for example, set somewhere in the range of 8 KHz to 12 KHz. When the audit response message is sent, the bandwidth would typically exceed the predetermined bandwidth.

(vi) Only when the transmitted bandwidth of the signal exceeds the predetermined bandwidth, the Wireless Location System initiates location processing.

Estimate Combination Method For Improving Location Accuracy

The accuracy of the location estimate provided by the Wireless Location System may be improved by combining multiple statistically-independent location estimates made while

the wireless transmitter is maintaining its position. Even when a wireless transmitter is perfectly stationary, the physical and RF environment around a wireless transmitter is constantly changing. For example, vehicles may change their position or another wireless transmitter which had caused a collision during one location estimate may have stopped transmitting or changed its position so as to no longer collide during subsequent location estimates. The location estimate provided by the Wireless Location System will therefore change for each transmission, even if consecutive transmissions are made within a very short period of time, and each location estimate is statistically independent of the other estimates, particularly with respect to the errors caused by the changing environment.

When several consecutive statistically independent location estimates are made for a wireless transmitter that has not changed its position, the location estimates will tend to cluster about the true position. The Wireless Location System combines the location estimates using a weighted average or other similar mathematical construct to determine the improved estimate. The use of a weighted average is aided by the assignment of a quality factor to each independent location estimate. This quality factor may be based upon, for example, the correlation values, confidence interval, or other similar measurements derived from the location processing for each independent estimate. The Wireless Location System optionally uses several methods to obtain multiple independent transmissions from the wireless transmitter, including (i) using its interface to the wireless communications system for the Make Transmit command; (ii) using multiple consecutive bursts from a time slot based air interface protocol, such as TDMA or GSM; or (iii) dividing a voice channel transmission into multiple segments over a period of time and performing location processing independently for each segment. As the Wireless Location System increases the number of independent location estimates being combined into the final location estimate, it monitors a statistic indicating the quality of the cluster. If the statistic is below a prescribed threshold value, then the Wireless Location System assumes that the wireless transmitter is maintaining its position. If the statistic rises above the prescribed threshold value, the Wireless Location System assume that the wireless transmitter is not maintaining its position and therefore ceases to perform additional location estimates. The statistic indicating the quality of the cluster may be, for example, a standard deviation calculation or a root mean square (RMS) calculation for the individual

location estimates being combined together and with respect to the dynamically calculated combined location estimate. When reporting a location record to a requesting application, the Wireless Location System indicates, using a field in the location record, the number of independent location estimate combined together to produce the reported location estimate.

Another exemplary process for obtaining and combining multiple location estimates will now be explained with reference to Figures 11A-11D. Figures 11A, 11B and 11C schematically depict the well-known "origination", "page response," and "audit" sequences of a wireless communications system. As shown in Figure 11A, the origination sequence (initiated by the wireless phone to make a call) may require two transmissions from the wireless transmitter, an "originate" signal and an "order confirmation" signal. The order confirmation signal is sent in response to a voice channel assignment from the wireless communications system (e.g., MSC). Similarly, as shown in Figure 11B, a page sequence may involve two transmissions from the wireless transmitter. The page sequence is initiated by the wireless communications system, e.g., when the wireless transmitter is called by another phone. After being paged, the wireless transmitter transmits a page response; and then, after being assigned a voice channel, the wireless transmitter transmits an order confirmation signal. The audit process, in contrast, elicits a single reverse transmission, an audit response signal. An audit and audit response sequence has the benefit of not ringing the wireless transmitter which is responding.

The manner in which these sequences may be used to locate a phone with improved accuracy will now be explained. According to the present invention, for example, a stolen phone, or a phone with a stolen serial number, is repeatedly pinged with an audit signal, which forces it to respond with multiple audit responses, thus permitting the phone to be located with greater accuracy. To use the audit sequence, however, the Wireless Location System sends the appropriate commands using its interface to the wireless communications system, which sends the audit message to the wireless transmitter. The Wireless Location System can also force a call termination (hang up) and then call the wireless transmitter back using the standard ANI code. The call can be terminated either by verbally instructing the mobile user to disconnect the call, by disconnecting the call at

the landline end of the call, or by sending an artificial over-the-air disconnect message to the base station. This over-the-air disconnect message simulates the pressing of the "END" button on a mobile unit. The call-back invokes the above-described paging sequence and forces the phone to initiate two transmissions that can be utilized to make location estimates.

Referring now to Figure 11D, the inventive high accuracy location method will now be summarized. First, an initial location estimate is made. Next, the above-described audit or "hang up and call back" process is employed to elicit a responsive transmission from the mobile unit, and then a second location estimate is made. Whether the audit or "hang up and call back" process is used will depend on whether the wireless communications system and wireless transmitter have both implemented the audit functionality. Steps second and third steps are repeated to obtain however many independent location estimates are deemed to be necessary or desirable, and ultimately the multiple statistically-independent location estimates are combined in an average, weighted average, or similar mathematical construct to obtain an improved estimate. The use of a weighted average is aided by the assignment of a quality factor to each independent location estimate. This quality factor may be based upon a correlation percentage, confidence interval, or other similar measurements derived from the location calculation process.

Bandwidth Synthesis Method For Improving Location Accuracy

The Wireless Location System is further capable of improving the accuracy of location estimates for wireless transmitters whose bandwidth is relatively narrow using a technique of artificial bandwidth synthesis. This technique can applied, for example, to those transmitters that use the AMPS, NAMPS, TDMA, and GSM air interface protocols and for which there are a large number of individual RF channels available for use by the wireless transmitter. For exemplary purposes, the following description shall refer to AMPS-specific details; however, the description can be easily altered to apply to other protocols. This method relies on the principle that each wireless transmitter is operative to transmit only narrowband signals at frequencies spanning a predefined wide band of frequencies that is wider than the bandwidth of the individual narrowband signals transmitted by the wireless transmitter. This method also relies on the aforementioned interface between the

Wireless Location System and the wireless communications system over which the WLS can command the wireless communications system to make a wireless transmitter handoff or switch to another frequency or RF channel. By issuing a series of commands, the Wireless Location System can force the wireless transmitter to switch sequentially and in a controlled manner to a series of RF channels, allowing the WLS effectively to synthesize a wider band received signal from the series of narrowband transmitted signals for the purpose of location processing.

In a presently preferred embodiment of the invention, the bandwidth synthesis means includes means for determining a wideband phase versus frequency characteristic of the transmissions from the wireless transmitter. For example, the narrowband signals typically have a bandwidth of approximately 20 KHz and the predefined wide band of frequencies spans approximately 12.5 MHz, which in this example, is the spectrum allocated to each cellular carrier by the FCC. With bandwidth synthesis, the resolution of the TDOA measurements can be increased to about 1/12.5 MHz; i.e., the available time resolution is the reciprocal of the effective bandwidth.

A wireless transmitter, a calibration transmitter (if used), SCS's 10A, 10B and 10C, and a TLP 12 are shown in Figure 12A. The location of the calibration transmitter and all three SCS's are accurately known *a priori*. Signals, represented by dashed arrows in Figure 12A, are transmitted by the wireless transmitter and calibration transmitter, and received at SCS's 10A, 10B and 10C, and processed using techniques previously described. During the location processing, RF data from one SCS (e.g. 10B) is cross-correlated (in the time or frequency domain) with the data stream from another SCS (e.g. 10C) separately for each transmitter and for each pair of SCS's 10 to generate TDOA estimates $TDOA_{23}$ and $TDOA_{13}$. An intermediate output of the location processing is a set of coefficients representing the complex cross-power as a function of frequency (e.g., R_{23}).

For example, if X(f) is the Fourier transform of the signal x(t) received at a first site and Y(f) is the Fourier transform of the signal y(t) received at a second site, then the complex cross-power $R(f)=X(f)Y^*(f)$, where Y^* is the complex conjugate of Y. The phase angle of R(f) at any frequency f equals the phase of X(f) minus the phase of Y(f). The phase angle

of R(f) may be called the fringe phase. In the absence of noise, interference, and other errors, the fringe phase is a perfectly linear function of frequency within a (contiguous) frequency band observed; and slope of the line is minus the interferometric group delay, or TDOA; the intercept of the line at the band center frequency, equal to the average value of the phase of R(f), is called "the" fringe phase of the observation when reference is being made to the whole band. Within a band, the fringe phase may be considered to be a function of frequency.

The coefficients obtained for the calibration transmitter are combined with those obtained for the wireless transmitter and the combinations are analyzed to obtain calibrated TDOA measurements $TDOA_{23}$ and $TDOA_{13}$, respectively. In the calibration process, the fringe phase of the calibration transmitter is subtracted from the fringe phase of the wireless transmitter in order to cancel systematic errors that are common to both. Since each original fringe phase is itself the difference between the phases of signals received at two SCS's 10, the calibration process is often called *double-differencing* and the calibrated result is said to be *doubly-differenced.* TDOA estimate T-ij is a maximum-likelihood estimate of the time difference of arrival (TDOA), between sites i and j, of the signal transmitted by the wireless transmitter, calibrated and also corrected for multipath propagation effects on the signals. TDOA estimates from different pairs of cell sites are combined to derive the location estimate. It is well known that more accurate TDOA estimates can be obtained by observing a wider bandwidth. It is generally not possible to increase the "instantaneous" bandwidth of the signal transmitted by a wireless transmitter, but it is possible to command a wireless transmitter to switch from one frequency channel to another so that, in a short time, a wide bandwidth can be observed.

In a typical non-wireline cellular system, for example, channels 313-333 are control channels and the remaining 395 channels are voice channels. The center frequency of a wireless transmitter transmitting on voice RF channel number 1 (RVC 1) is 826.030 MHz and the center-to-center frequency spacing of successive channels of 0.030 MHz. The number of voice channels assigned to each cell of a typical seven-cell frequency-reuse block is about 57 (i.e., 395 divided by 7) and these channels are distributed throughout the 395-channel range, spaced every 7 channels. Note then that each cell site used in an

AMPS system has channels that span the entire 12.5 MHz band allocated by the FCC. If, for example, we designate cells of each frequency set in a re-use pattern as cells "A" through "G", the channel numbers assigned to the "A" cell(s) might be 1, 8, 15, 22, ..., 309; the numbers of the channels assigned to the "B" cells are determined by adding 1 to the "A" channel numbers; and so on through G.

The method begins when the wireless transmitter has been assigned to a voice RF channel, and the Wireless Location System has triggered location processing for the transmissions from the wireless transmitter. As part of the location processing, the TDOA estimates $TDOA_{13}$ and $TDOA_{23}$ combined may have, for example, a standard deviation error of 0.5 microsecond. The method combining measurements from different RF channels exploits the relation between TDOA, fringe phase, and radio frequency. Denote the "true" value of the group delay or TDOA, i.e., the value that would be observed in the absence of noise, multipath, and any instrumental error, by τ; similarly, denote the true value of fringe phase by ϕ; and denote the radio frequency by f. The fringe phase ϕ is related to τ and f by:

$$\phi = -f\tau + n \qquad \text{(Eq. 1)}$$

where ϕ is measured in cycles, f in Hz and τ in seconds; and n is an integer representing the intrinsic integer-cycle ambiguity of a doubly-differenced phase measurement. The value of n is unknown *a priori* but is the same for observations at contiguous frequencies, i.e., within any one frequency channel. The value of n is generally different for observations at separated frequencies. τ can be estimated from observations in a single frequency channel is, in effect, by fitting a straight line to the fringe phase observed as a function of frequency within the channel. The slope of the best-fitting line equals minus the desired estimate of τ. In the single-channel case, n is constant and so Eq. 1 can be differentiated to obtain:

$$d\phi/df = -\tau \qquad \text{(Eq. 2).}$$

Independent estimates of τ are obtainable by straight-line fitting to the observations of ϕ vs. f separately for each channel, but when two separate (non-contiguous) frequency channels are observed, a single straight line will not generally fit the observations of ϕ vs. f from both channels because, in general, the integer n has different values for the two channels. However, under certain conditions, it is possible to determine and remove the difference between these two integer values and then to fit a single straight line to the entire set of phase data spanning both channels. The slope of this straight line will be much better determined because it is based on a wider range of frequencies. Under certain conditions, the uncertainty of the slope estimate is inversely proportional to the frequency span.

In this example, suppose that the wireless transmitter has been assigned to voice RF channel 1. The radio frequency difference between channels 1 and 416 is so great that initially the difference between the integers n_1 and n_{416} corresponding to these channels cannot be determined. However, from the observations in either or both channels taken separately, an initial TDOA estimate τ_0 can be derived. Now the Wireless Location System commands the wireless communications system to make the wireless transmitter to switch from channel 1 to channel 8. The wireless transmitter's signal is received in channel 8 and processed to update or refine the estimate τ_0. From τ_0, the "theoretical" fringe-phase ϕ_0 as a function of frequency can be computed, equal to $(-f\tau_0)$. The difference between the actually observed phase ϕ and the theoretical function ϕ_0 can be computed, where the actually observed phase equals the true phase within a very small fraction, typically 1/50th, of a cycle:

$$\phi-\phi_0 = -f(\tau-\tau_0) + n_1 \text{ or } n_8\text{, depending on the channel} \qquad \text{(Eq. 3)}$$

or

$$\Delta\phi = -\Delta f\tau-n_1 \text{ or } n_8\text{, depending on the channel} \qquad \text{(Eq. 4)}$$

where $\Delta\phi \equiv \phi-\phi_0$ and $\Delta\tau \equiv \tau-\tau_0$. Equation (4) is graphed in Figure 12B, depicting the difference, $\Delta\phi$, between the observed fringe phase ϕ and the value ϕ_0 computed from the initial TDOA estimate τ_0, versus frequency f for channels 1 and 8.

For the 20 KHz-wide band of frequencies corresponding to channel 1, a graph of $\Delta\phi$ vs. f is typically a horizontal straight line. For the 20 KHz-wide band of frequencies corresponding to channel 8, the graph of $\Delta\phi$ vs. f is also horizontal straight line. The slopes of these line segments are generally nearly zero because the quantity ($f\Delta\tau$) usually does not vary by a significant fraction of a cycle within 20 KHz, because $\Delta\tau$ is minus the error of the estimate τ_0. The magnitude of this error typically will not exceed 1.5 microseconds (3 times the standard deviation of 0.5 microseconds in this example), and the product of 1.5 microseconds and 20 KHz is under 4% of a cycle. In Figure 12B, the graph of $\Delta\phi$ for channel 1 is displaced vertically from the graph of $\Delta\phi$ for channel 8 by a relatively large amount because the difference between n_1 and n_8 can be arbitrarily large. This vertical displacement, or difference between the average values of $\Delta\phi$ for channels 1 and 8, will (with extremely high probability) be within ±0.3 cycle of the true value of the difference, n_1 and n_8, because the product of the maximum likely magnitude of $\Delta\tau$ (1.5 microseconds) and the spacing of channels 1 and 8 (210 KHz) is 0.315 cycle. In other words, the difference $n_1 - n_8$ is equal to the difference between the average values of $\Delta\phi$ for channels 1 and 8, rounded to the nearest integer. After the integer difference $n_1 - n_8$ is determined by this rounding procedure, the integer $\Delta\phi$ is added for channel 8 or subtracted from $\Delta\phi$ for channel 1. The difference between the average values of $\Delta\phi$ for channels 1 and 8 is generally equal to the error in the initial TDOA estimate, τ_0, times 210 KHz. The difference between the average values of $\Delta\phi$ for channels 1 and 8 is divided by 210 KHz and the result is added to τ_0 to obtain an estimate of τ, the true value of the TDOA; this new estimate can be significantly more accurate than τ_0.

This frequency-stepping and TDOA-refining method can be extended to more widely spaced channels to obtain yet more accurate results. If τ_1 is used to represent the refined result obtained from channels 1 and 8, τ_0 can be replaced by τ_1 in the just-described method; and the Wireless Location System can command the wireless communications system to make the wireless transmitter switch, e.g., from channel 8 to channel 36; then τ_1 can be used to determine the integer difference $n_8 - n_{36}$ and a TDOA estimate can be obtained based on the 1.05 MHz frequency span between channels 1 and 36. The

estimated can be labeled τ_2; and the wireless transmitter switched, e.g., from channel 36 to 112, and so on. In principle, the full range of frequencies allocated to the cellular carrier can be spanned. The channel numbers (1, 8, 36, 112) used in this example are, of course, arbitrary. The general principle is that an estimate of the TDOA based on a small frequency span (starting with a single channel) is used to resolve the integer ambiguity of the fringe phase difference between more widely separated frequencies. The latter frequency separation should not be too large; it is limited by the uncertainty of the prior estimate of TDOA. In general, the worst-case error in the prior estimate multiplied by the frequency difference may not exceed 0.5 cycle.

If the very smallest (e.g., 210 KHz) frequency gap between the most closely spaced channels allocated to a particular cell cannot be bridged because the worst-case uncertainty of the single-channel TDOA estimate exceeds 2.38 microseconds (equal to 0.5 cycle divided by 0.210 MHz), the Wireless Location System commands the wireless communications system to force the wireless transmitter hand-off from one cell site to another (e.g. from one frequency group to another), such that the frequency step is smaller. There is a possibility of misidentifying the integer difference between the phase differences ($\Delta\phi$'s) for two channels, e.g., because the wireless transmitter moved during the handoff from one channel to the other. Therefore, as a check, the Wireless Location System may reverse each handoff (e.g., after switching from channel 1 to channel 8, switch from channel 8 back to channel 1) and confirm that the integer-cycle difference determined has precisely the same magnitude and the opposite sign as for the "forward" hand-off. A significantly nonzero velocity estimate from the single-channel FDOA observations can be used to extrapolate across the time interval involved in a channel change. Ordinarily this time interval can be held to a small fraction of 1 second. The FDOA estimation error multiplied by the time interval between channels must be small in comparison with 0.5 cycle. The Wireless Location System preferably employs a variety of redundancies and checks against integer-misidentification.

Directed Retry for 911

Another inventive aspect of the Wireless Location System relates to a "directed retry" method for use in connection with a dual-mode wireless communications

system supporting at least a first modulation method and a second modulation method. In such a situation, the first and second modulation methods are assumed to be used on different RF channels (i.e. channels for the wireless communications system supporting a WLS and the PCS system, respectively). It is also assumed that the wireless transmitter to be located is capable of supporting both modulation methods, i.e. is capable of dialing "911" on the wireless communications system having Wireless Location System support.

For example, the directed retry method could be used in a system in which there are an insufficient number of base stations to support a Wireless Location System, but which is operating in a region served by a Wireless Location System associated with another wireless communications system. The "first" wireless communications system could be a cellular telephone system and the "second" wireless communications system could be a PCS system operating within the same territory as the first system. According to the invention, when the mobile transmitter is currently using the second (PCS) modulation method and attempts to originate a call to 911, the mobile transmitter is caused to switch automatically to the first modulation method, and then to originate the call to 911 using the first modulation method on one of the set of RF channels prescribed for use by the first wireless communications system. In this manner, location services can be provided to customers of a PCS or like system that does is not served by its own Wireless Location System.

Conclusion

The true scope the present invention is not limited to the presently preferred embodiments disclosed herein. For example, the foregoing disclosure of a presently preferred embodiment of a Wireless Location System uses explanatory terms, such as Signal Collection System (SCS), TDOA Location Processor (TLP), Applications Processor (AP), and the like, which should not be construed so as to limit the scope of protection of the following claims, or to otherwise imply that the inventive aspects of the Wireless Location System are limited to the particular methods and apparatus disclosed. Moreover, as will be understood by those skilled in the art, many of the inventive aspects disclosed herein may

be applied in location systems that are not based on TDOA techniques. For example, the processes by which the Wireless Location System uses the Tasking List, etc. can be applied to non-TDOA systems. In such non-TDOA systems, the TLP's described above would not be required to perform TDOA calculations. Similarly, the invention is not limited to systems employing SCS's constructed as described above, nor to systems employing AP's meeting all of the particulars described above. The SCS's, TLP's and AP's are, in essence, programmable data collection and processing devices that could take a variety of forms without departing from the inventive concepts disclosed herein. Given the rapidly declining cost of digital signal processing and other processing functions, it is easily possible, for example, to transfer the processing for a particular function from one of the functional elements (such as the TLP) described herein to another functional element (such as the SCS or AP) without changing the inventive operation of the system. In many cases, the place of implementation (i.e. the functional element) described herein is merely a designer's preference and not a hard requirement. Accordingly, except as they may be expressly so limited, the scope of protection of the following claims is not intended to be limited to the specific embodiments described above.

CLAIMS

What is claimed is:

1. A method for use in a Wireless Location System in locating a mobile transmitter, comprising the steps of:

(a) monitoring the bandwidth of a reverse voice channel (RVC) signal;

(b) determining whether said bandwidth exceeds a predetermined threshold; and

(c) calculating the location of said mobile transmitter if and only if said bandwidth exceeds said predetermined threshold.

2. A method as recited in claim 1, wherein said mobile transmitter is carried by a user, the method further comprises the step of, prior to step (c) and after determining in step (b) that said bandwidth does not exceed said threshold, taking an action to cause the mobile transmitter to transmit an RVC signal with a larger bandwidth.

3. A method as recited in claim 2, further comprising asking said user to dial a number of at least 9 digits.

4. A method as recited in claim 2, further comprising asking an emergency dispatcher to instruct said user to dial a number of at least 9 digits.

5. A method as recited in claim 1, wherein said predetermined threshold is within the range of approximately 8 to 12 KHz.

6. A method as recited in claim 5, wherein said predetermined threshold is approximately 10 KHz.

7. A method as recited in claim 5, wherein said mobile transmitter is carried by a user and the method further comprises the step of, prior to step (c) and after determining in step (b) that said bandwidth does not exceed said threshold, taking an action to cause the mobile transmitter to transmit an RVC signal of increased bandwidth.

8. A method as recited in claim 2, wherein the method further comprises sending an audit message to the mobile transmitter.

9. A method as recited in claim 8, wherein the audit message is sent automatically to the mobile transmitter upon command from the wireless location system.

10. A method for use in a Wireless Location System in locating a mobile transmitter in an emergency situation, comprising the steps of:

(a) upon determining that said emergency situation exists, monitoring a bandwidth of a reverse voice channel (RVC) signal transmitted by said mobile transmitter;

(b) determining whether said bandwidth exceeds a predetermined threshold;

(c) if said bandwidth exceeds said predetermined threshold, measuring the location of said mobile transmitter; and

(d) if said bandwidth does not exceed said predetermined threshold, performing a predetermined action to increase said bandwidth and subsequently measuring the location of said mobile transmitter.

11. A method as recited in claim 10, wherein said mobile transmitter is carried by a user and said predetermined action comprises requesting the user to take an action to cause the mobile transmitter to transmit an RVC signal comprising a prescribed number of bits.

12. A method as recited in claim 11, wherein said predetermined action comprises asking said user to a number of at least 9 digits.

13. A method as recited in claim 11, wherein said predetermined action comprises asking an emergency dispatcher to instruct said user to dial a number of at least 9 digits.

14. A method as recited in claim 10, wherein said predetermined threshold is within the range of approximately 8 to 12 KHz.

15. A method as recited in claim 14, wherein said predetermined threshold is approximately 10 KHz.

16. A method as recited in claim 12, wherein said mobile transmitter is carried by a user and said predetermined action comprises requesting the user to take an action to cause the mobile transmitter to transmit an RVC signal comprising a prescribed number of bits.

17. A method as recited in claim 16, wherein said predetermined action comprises asking said user to dial a 9-digit number.

18. A method as recited in claim 16, wherein said predetermined action comprises asking an emergency dispatcher to instruct said user to dial a 9-digit number.

19. A method as recited in claim 10, wherein said predetermined action comprises sending an audit message to the mobile transmitter.

20. A method as recited in claim 19, wherein the audit message is sent automatically to the mobile transmitter upon command from the wireless location system.

21. A wireless location system, comprising:

(a) means for monitoring the bandwidth of a reverse voice channel (RVC) signal from a mobile transmitter;

(b) means for determining whether said bandwidth exceeds a predetermined threshold; and

(c) means for calculating the location of said mobile transmitter if and only if said bandwidth exceeds said predetermined threshold.

22. A system as recited in claim 21, wherein said mobile transmitter is carried by a user, the system further comprising means for taking an action to cause the mobile transmitter to transmit an RVC signal with a larger bandwidth.

23. A system as recited in claim 22, further comprising means for asking said user to dial a number of at least 9 digits.

24. A system as recited in claim 22, further comprising means for asking an emergency dispatcher to instruct said user to dial a number of at least 9 digits.

25. A system as recited in claim 21, wherein said predetermined threshold is within the range of approximately 8 to 12 KHz.

26. A system as recited in claim 25, wherein said predetermined threshold is approximately 10 KHz.

27. A system as recited in claim 25, wherein said mobile transmitter is carried by a user and the system further comprises means for taking an action to cause the mobile transmitter to transmit an RVC signal of increased bandwidth.

28. A system as recited in claim 22, wherein the system further comprises means for sending an audit message to the mobile transmitter.

29. A system as recited in claim 28, comprising means for sending the audit message automatically to the mobile transmitter upon command.

30. A method for use in a wireless location system for locating a mobile transmitter transmitting a signal with a bandwidth, comprising: monitoring the bandwidth, determining whether the bandwidth exceeds a predetermined threshold, and calculating location only if the bandwidth exceeds the threshold.

31. A method as recited in claim 30, wherein the mobile transmitter is carried by a user, and further comprising taking an action to cause the mobile transmitter to transmit a reverse voice channel (RVC) signal with a larger bandwidth.

32. A method as recited in claim 31, wherein the action comprises asking the user to dial at least 9 digits.

33. A method as recited in claim 31, wherein the action comprises asking an emergency dispatcher to instruct the user to dial 9 digits.

34. A method as recited in claim 31, wherein the action comprises causing the sending of an audit message to the mobile transmitter.

35. A method as recited in claim 34, wherein the audit message is sent automatically upon command from the wireless location system.

36. A method as recited in claim 30, wherein the predetermined threshold is within the range of 8 KHz to 12 KHz.

37. A method as recited in claim 36, wherein the predetermined threshold is approximately 10 KHz.

38. A method as recited in claim 37, wherein the mobile transmitter is carried by a user, and further comprising taking an action to cause the mobile transmitter to transmit a reverse voice channel (RVC) signal with a larger bandwidth.

39. A method for use in a wireless location system for locating a mobile transmitter, comprising: determining that an emergency situation exists; monitoring the bandwidth of a reverse voice channel (RVC) signal from the mobile transmitter; determining whether the bandwidth exceeds a predetermined threshold; measuring the location of the mobile transmitter if the bandwidth does exceed the threshold; and, if the bandwidth is less than the threshold, performing a predetermined action to increase the bandwidth and then measuring the location of the mobile transmitter.

40. A method as recited in claim 39, wherein the mobile transmitter is carried by a user, and further comprising taking an action to cause the mobile transmitter to transmit a reverse voice channel (RVC) signal with a prescribed number of bits.

41. A method as recited in claim 40, wherein the action comprises asking the user to dial at least 9 digits.

42. A method as recited in claim 40, wherein the action comprises asking an emergency dispatcher to instruct the user to dial 9 digits.

43. A method as recited in claim 40, wherein the action comprises causing an audit message to be sent to the mobile transmitter.

44. A method as recited in claim 43, wherein the audit message is sent automatically upon command from the wireless location system.

45. A method as recited in claim 39, wherein the predetermined threshold is within range of 8 KHz to 12 KHz.

46. A method as recited in claim 45, wherein the predetermined threshold is approximately 10 KHz.

47. A method as recited in claim 46, wherein the mobile transmitter is carried by a user, and further comprising taking an action to cause the mobile transmitter to transmit a reverse voice channel (RVC) signal with a larger bandwidth.

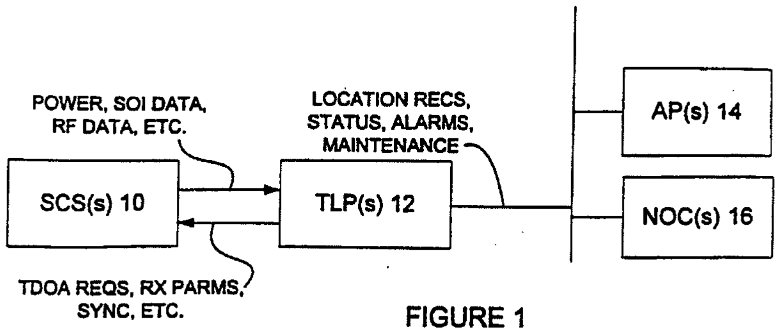


FIGURE 1

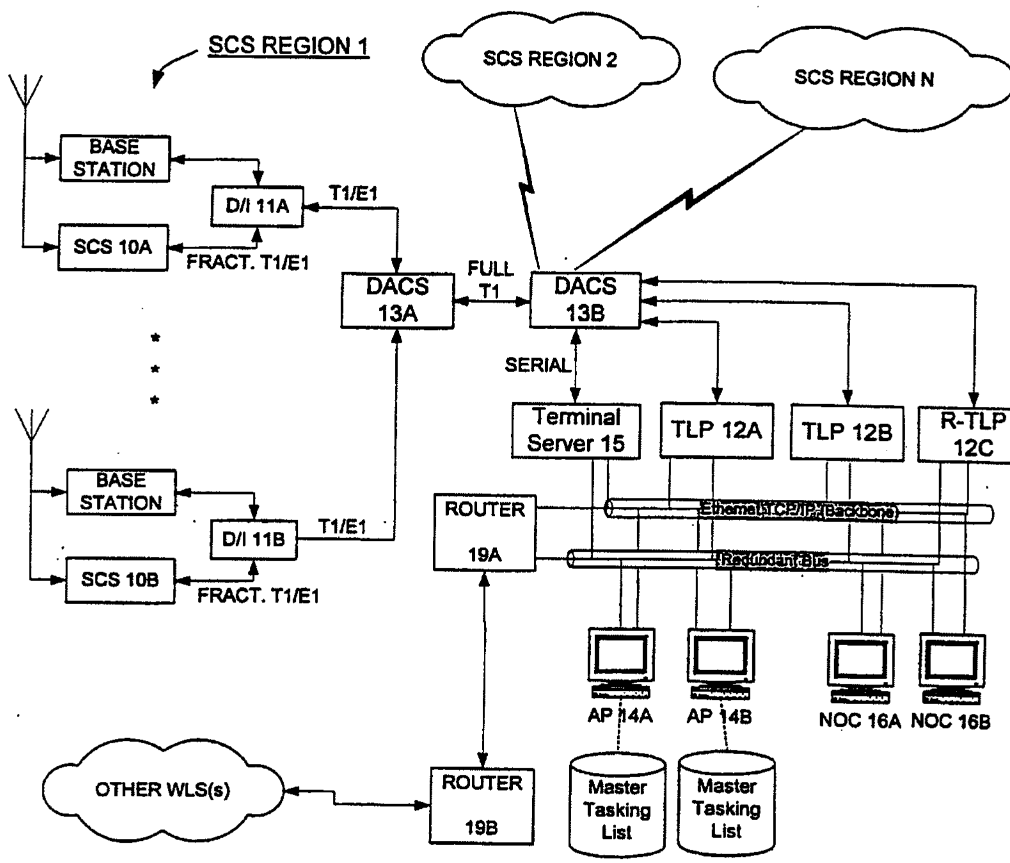


FIGURE 1A

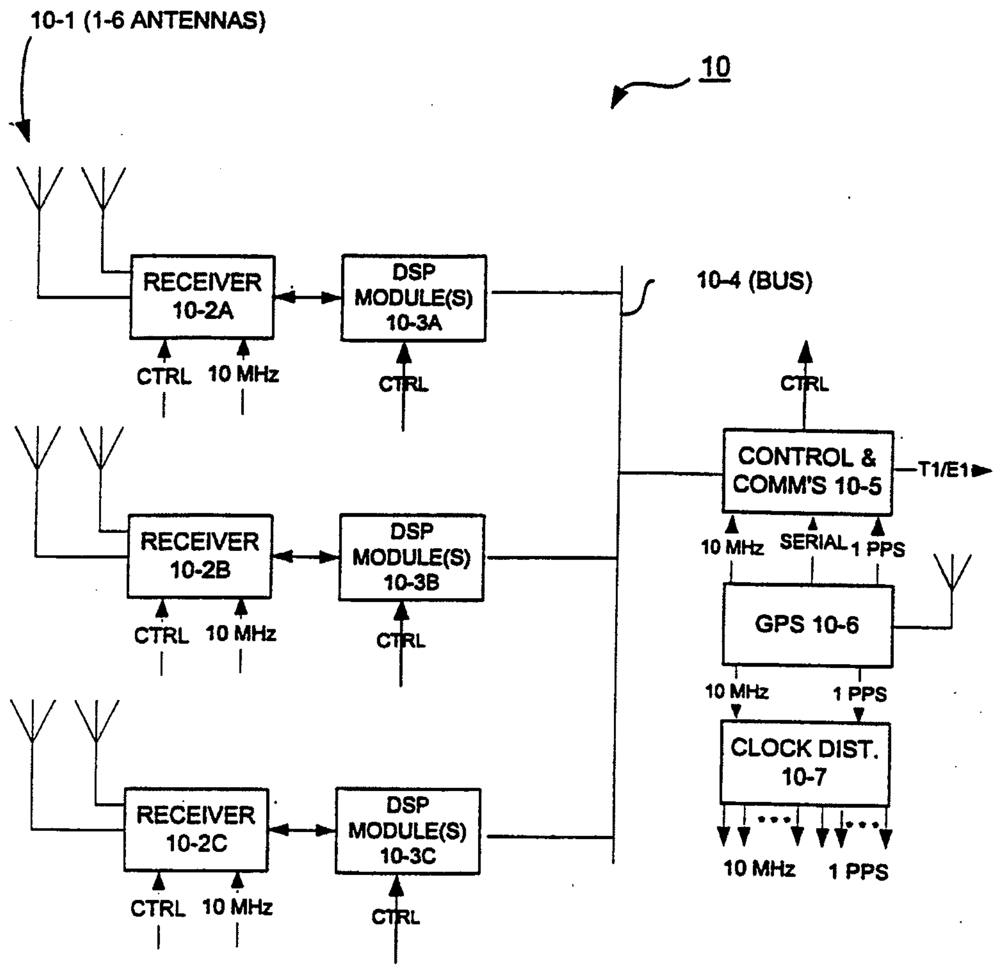

10-1 (1-6 ANTENNAS)
10
RECEIVER 10-2A
DSP MODULE(S) 10-3A
CTRL
10 MHz
CTRL
10-4 (BUS)
RECEIVER 10-2B
DSP MODULE(S) 10-3B
CTRL
10 MHz
CTRL
RECEIVER 10-2C
DSP MODULE(S) 10-3C
CTRL
10 MHz
CTRL
CTRL
CONTROL & COMM'S 10-5
T1/E1
10 MHz
SERIAL
1 PPS
GPS 10-6
10 MHz
1 PPS
CLOCK DIST. 10-7
10 MHz
1 PPS

FIGURE 2

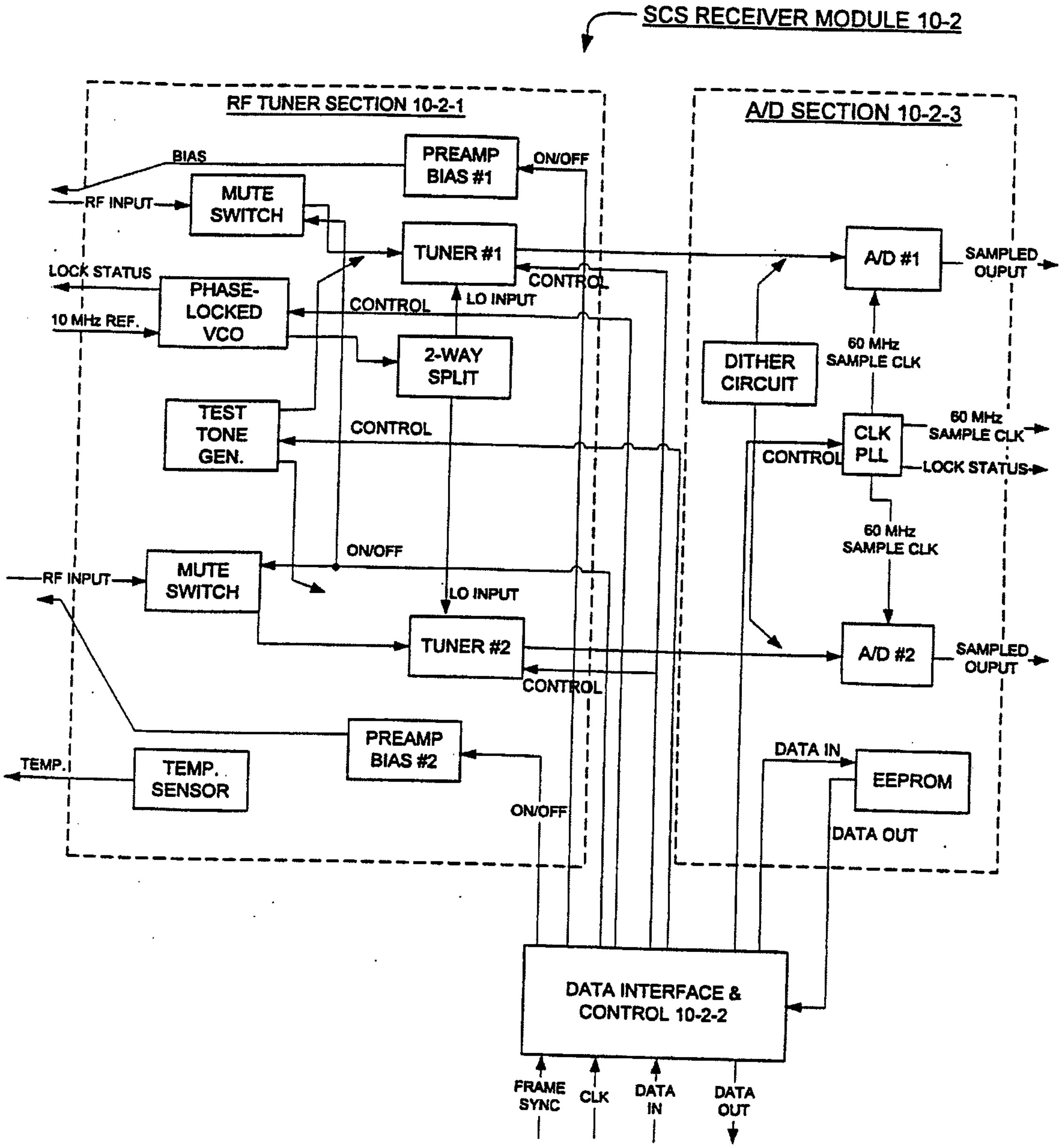

SCS RECEIVER MODULE 10-2
RF TUNER SECTION 10-2-1
A/D SECTION 10-2-3
BIAS
PREAMP BIAS #1
ON/OFF
RF INPUT
MUTE SWITCH
TUNER #1
A/D #1
SAMPLED OUPUT
LOCK STATUS
PHASE-LOCKED VCO
CONTROL
CONTROL
LO INPUT
10 MHz REF.
2-WAY SPLIT
DITHER CIRCUIT
60 MHz SAMPLE CLK
TEST TONE GEN.
CONTROL
CLK PLL
60 MHz SAMPLE CLK
CONTROL
LOCK STATUS
60 MHz SAMPLE CLK
ON/OFF
RF INPUT
MUTE SWITCH
LO INPUT
TUNER #2
A/D #2
SAMPLED OUPUT
CONTROL
PREAMP BIAS #2
DATA IN
EEPROM
TEMP.
TEMP. SENSOR
ON/OFF
DATA OUT
DATA INTERFACE & CONTROL 10-2-2
FRAME SYNC
CLK
DATA IN
DATA OUT

FIGURE 2A

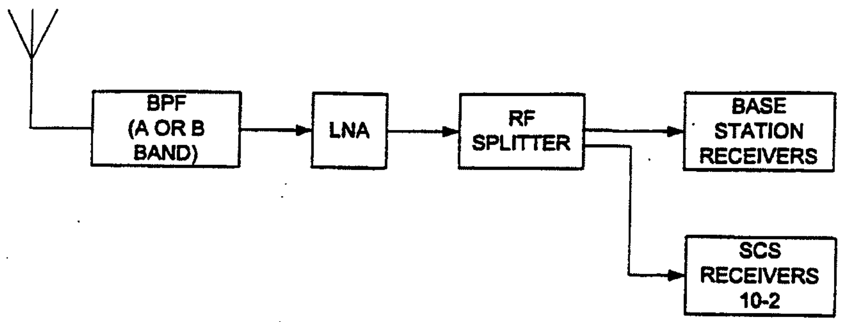


FIGURE 2B

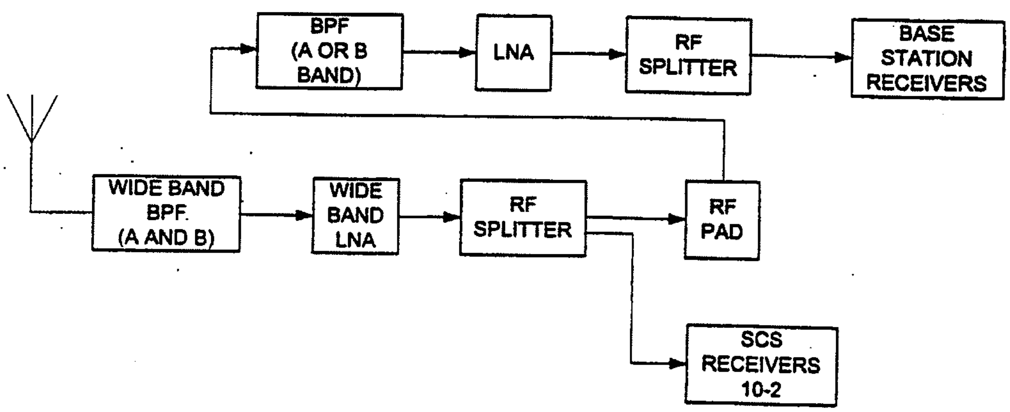


FIGURE 2C

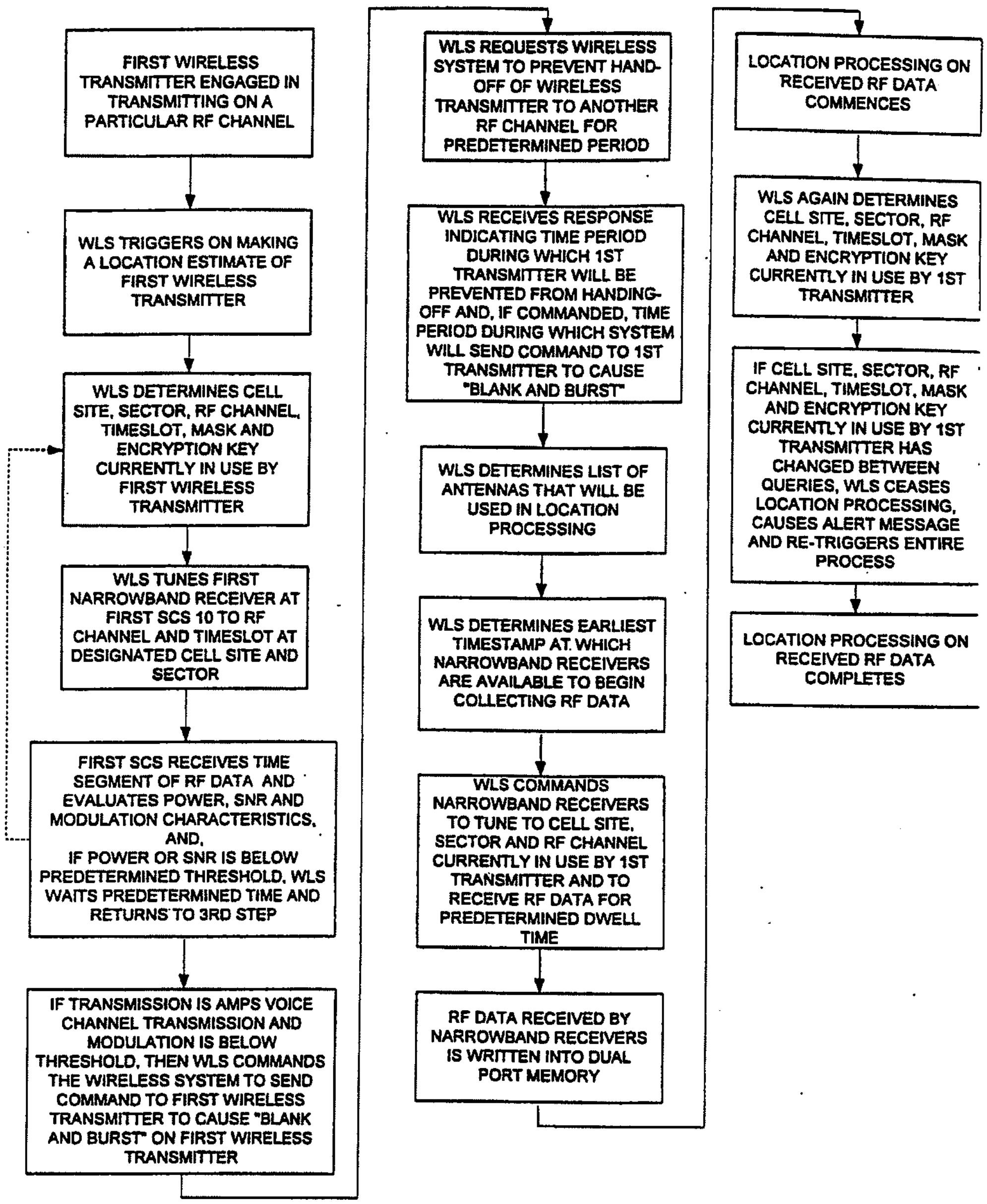

FIRST WIRELESS TRANSMITTER ENGAGED IN TRANSMITTING ON A PARTICULAR RF CHANNEL
WLS TRIGGERS ON MAKING A LOCATION ESTIMATE OF FIRST WIRELESS TRANSMITTER
WLS DETERMINES CELL SITE, SECTOR, RF CHANNEL, TIMESLOT, MASK AND ENCRYPTION KEY CURRENTLY IN USE BY FIRST WIRELESS TRANSMITTER
WLS TUNES FIRST NARROWBAND RECEIVER AT FIRST SCS 10 TO RF CHANNEL AND TIMESLOT AT DESIGNATED CELL SITE AND SECTOR
FIRST SCS RECEIVES TIME SEGMENT OF RF DATA AND EVALUATES POWER, SNR AND MODULATION CHARACTERISTICS, AND, IF POWER OR SNR IS BELOW PREDETERMINED THRESHOLD, WLS WAITS PREDETERMINED TIME AND RETURNS TO 3RD STEP
IF TRANSMISSION IS AMPS VOICE CHANNEL TRANSMISSION AND MODULATION IS BELOW THRESHOLD, THEN WLS COMMANDS THE WIRELESS SYSTEM TO SEND COMMAND TO FIRST WIRELESS TRANSMITTER TO CAUSE "BLANK AND BURST" ON FIRST WIRELESS TRANSMITTER
WLS REQUESTS WIRELESS SYSTEM TO PREVENT HAND-OFF OF WIRELESS TRANSMITTER TO ANOTHER RF CHANNEL FOR PREDETERMINED PERIOD
WLS RECEIVES RESPONSE INDICATING TIME PERIOD DURING WHICH 1ST TRANSMITTER WILL BE PREVENTED FROM HANDING-OFF AND, IF COMMANDED, TIME PERIOD DURING WHICH SYSTEM WILL SEND COMMAND TO 1ST TRANSMITTER TO CAUSE "BLANK AND BURST"
WLS DETERMINES LIST OF ANTENNAS THAT WILL BE USED IN LOCATION PROCESSING
WLS DETERMINES EARLIEST TIMESTAMP AT WHICH NARROWBAND RECEIVERS ARE AVAILABLE TO BEGIN COLLECTING RF DATA
WLS COMMANDS NARROWBAND RECEIVERS TO TUNE TO CELL SITE, SECTOR AND RF CHANNEL CURRENTLY IN USE BY 1ST TRANSMITTER AND TO RECEIVE RF DATA FOR PREDETERMINED DWELL TIME
RF DATA RECEIVED BY NARROWBAND RECEIVERS IS WRITTEN INTO DUAL PORT MEMORY
LOCATION PROCESSING ON RECEIVED RF DATA COMMENCES
WLS AGAIN DETERMINES CELL SITE, SECTOR, RF CHANNEL, TIMESLOT, MASK AND ENCRYPTION KEY CURRENTLY IN USE BY 1ST TRANSMITTER
IF CELL SITE, SECTOR, RF CHANNEL, TIMESLOT, MASK AND ENCRYPTION KEY CURRENTLY IN USE BY 1ST TRANSMITTER HAS CHANGED BETWEEN QUERIES, WLS CEASES LOCATION PROCESSING, CAUSES ALERT MESSAGE AND RE-TRIGGERS ENTIRE PROCESS
LOCATION PROCESSING ON RECEIVED RF DATA COMPLETES

FIGURE 2C-1

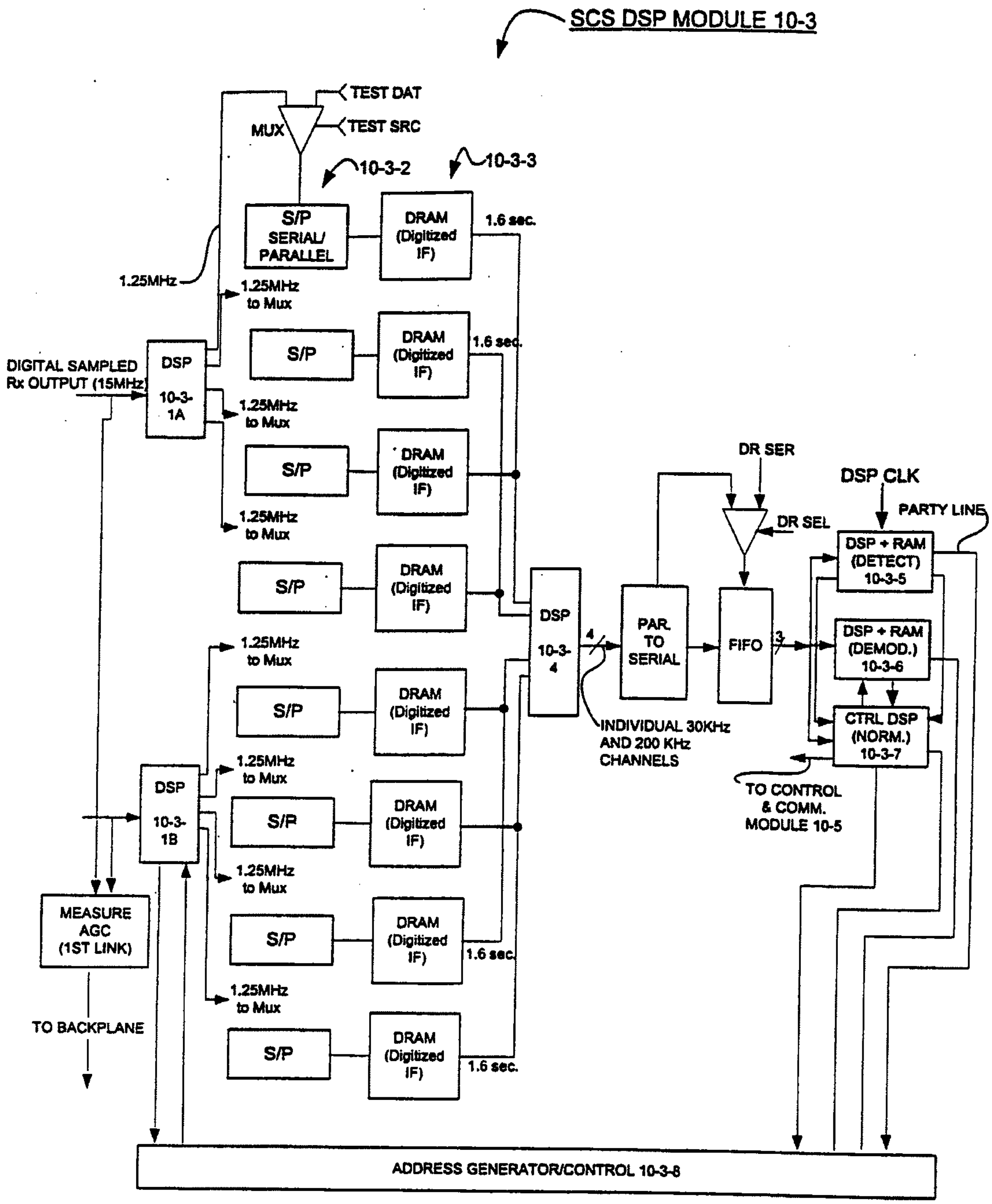

SCS DSP MODULE 10-3
TEST DAT
TEST SRC
MUX
10-3-2
10-3-3
S/P SERIAL/ PARALLEL
DRAM (Digitized IF)
1.6 sec.
1.25MHz
1.25MHz to Mux
S/P
DIGITAL SAMPLED Rx OUTPUT (15MHz)
DSP 10-3-1A
DSP 10-3-1B
DSP 10-3-4
DR SER
DR SEL
DSP CLK
PARTY LINE
DSP + RAM (DETECT) 10-3-5
DSP + RAM (DEMOD.) 10-3-6
CTRL DSP (NORM.) 10-3-7
PAR. TO SERIAL
FIFO
INDIVIDUAL 30KHz AND 200 KHz CHANNELS
TO CONTROL & COMM. MODULE 10-5
MEASURE AGC (1ST LINK)
TO BACKPLANE
ADDRESS GENERATOR/CONTROL 10-3-8

FIGURE 2D

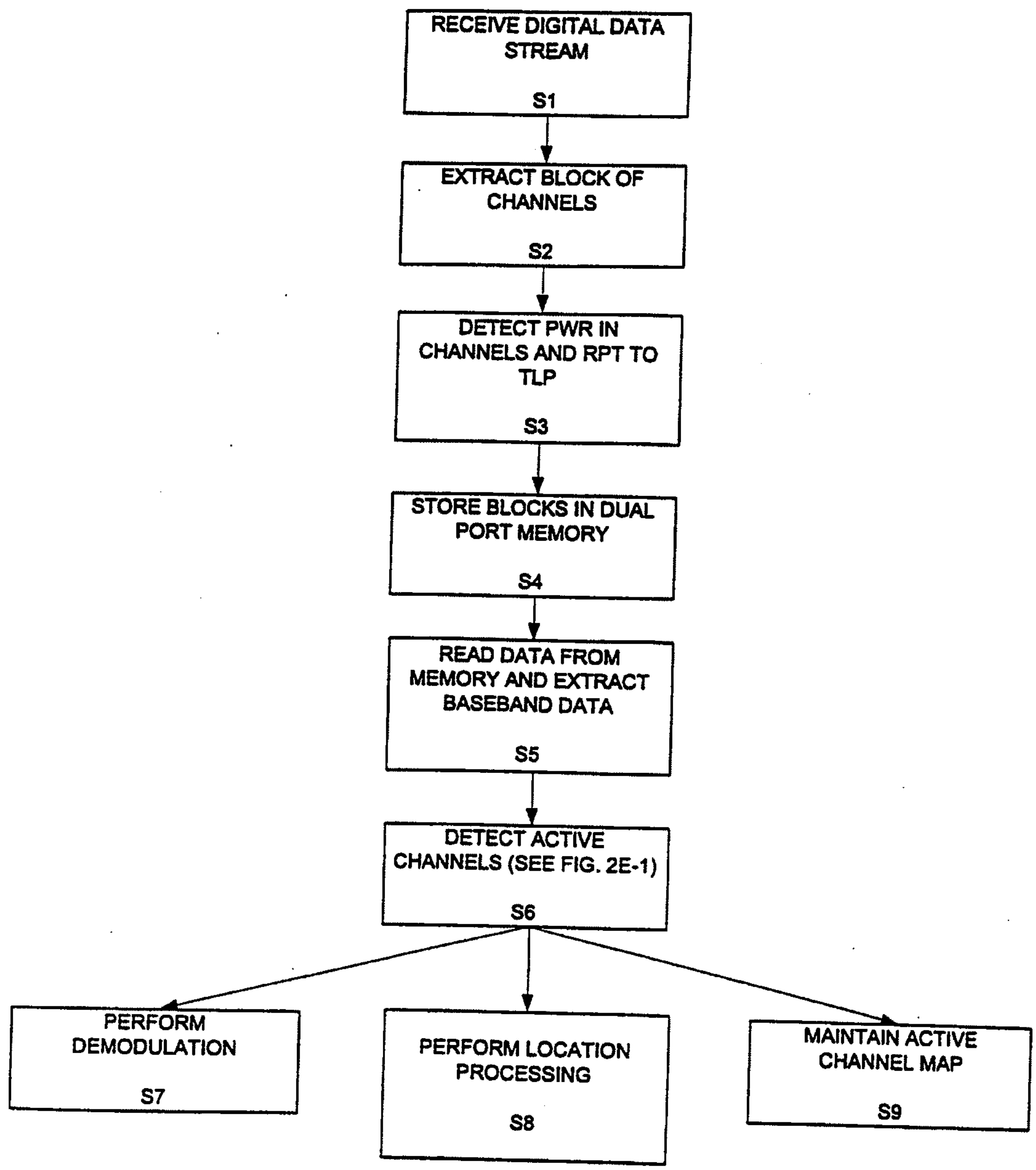

RECEIVE DIGITAL DATA STREAM
S1
EXTRACT BLOCK OF CHANNELS
S2
DETECT PWR IN CHANNELS AND RPT TO TLP
S3
STORE BLOCKS IN DUAL PORT MEMORY
S4
READ DATA FROM MEMORY AND EXTRACT BASEBAND DATA
S5
DETECT ACTIVE CHANNELS (SEE FIG. 2E-1)
S6
PERFORM DEMODULATION
S7
PERFORM LOCATION PROCESSING
S8
MAINTAIN ACTIVE CHANNEL MAP
S9

FIGURE 2E

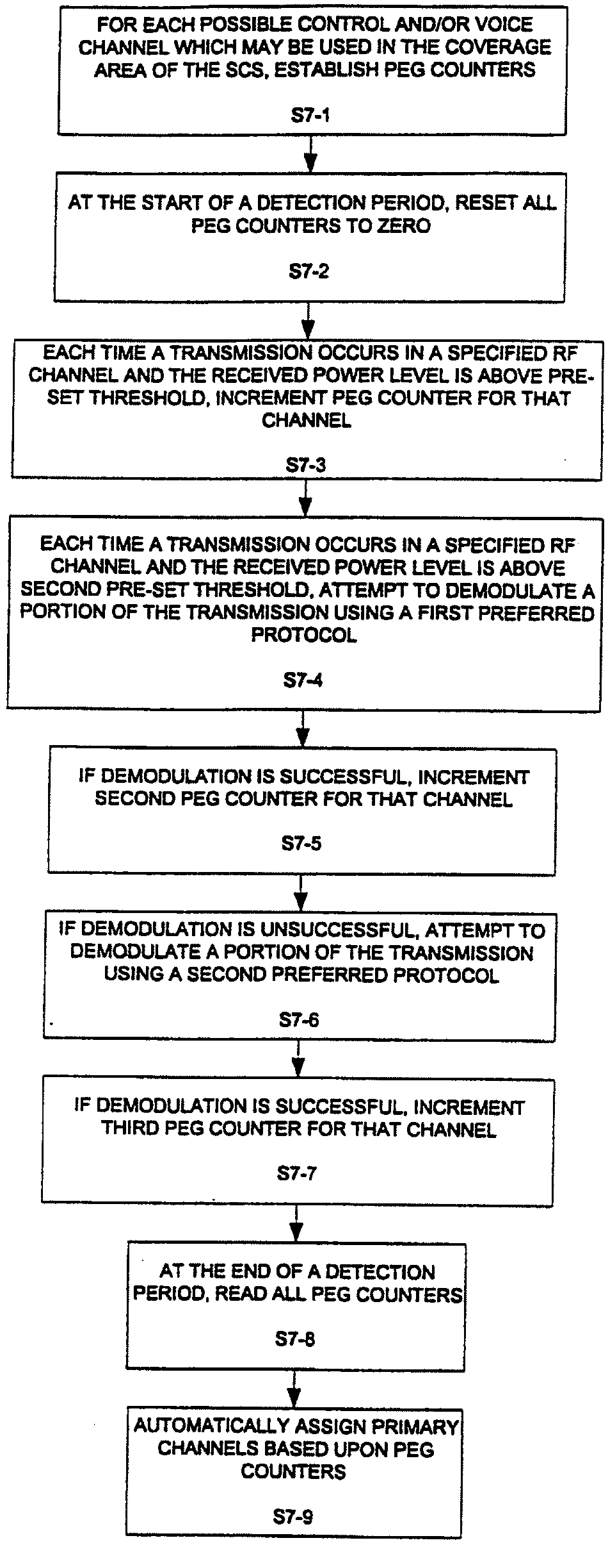

FOR EACH POSSIBLE CONTROL AND/OR VOICE CHANNEL WHICH MAY BE USED IN THE COVERAGE AREA OF THE SCS, ESTABLISH PEG COUNTERS
S7-1
AT THE START OF A DETECTION PERIOD, RESET ALL PEG COUNTERS TO ZERO
S7-2
EACH TIME A TRANSMISSION OCCURS IN A SPECIFIED RF CHANNEL AND THE RECEIVED POWER LEVEL IS ABOVE PRE-SET THRESHOLD, INCREMENT PEG COUNTER FOR THAT CHANNEL
S7-3
EACH TIME A TRANSMISSION OCCURS IN A SPECIFIED RF CHANNEL AND THE RECEIVED POWER LEVEL IS ABOVE SECOND PRE-SET THRESHOLD, ATTEMPT TO DEMODULATE A PORTION OF THE TRANSMISSION USING A FIRST PREFERRED PROTOCOL
S7-4
IF DEMODULATION IS SUCCESSFUL, INCREMENT SECOND PEG COUNTER FOR THAT CHANNEL
S7-5
IF DEMODULATION IS UNSUCCESSFUL, ATTEMPT TO DEMODULATE A PORTION OF THE TRANSMISSION USING A SECOND PREFERRED PROTOCOL
S7-6
IF DEMODULATION IS SUCCESSFUL, INCREMENT THIRD PEG COUNTER FOR THAT CHANNEL
S7-7
AT THE END OF A DETECTION PERIOD, READ ALL PEG COUNTERS
S7-8
AUTOMATICALLY ASSIGN PRIMARY CHANNELS BASED UPON PEG COUNTERS
S7-9

FIGURE 2E-1

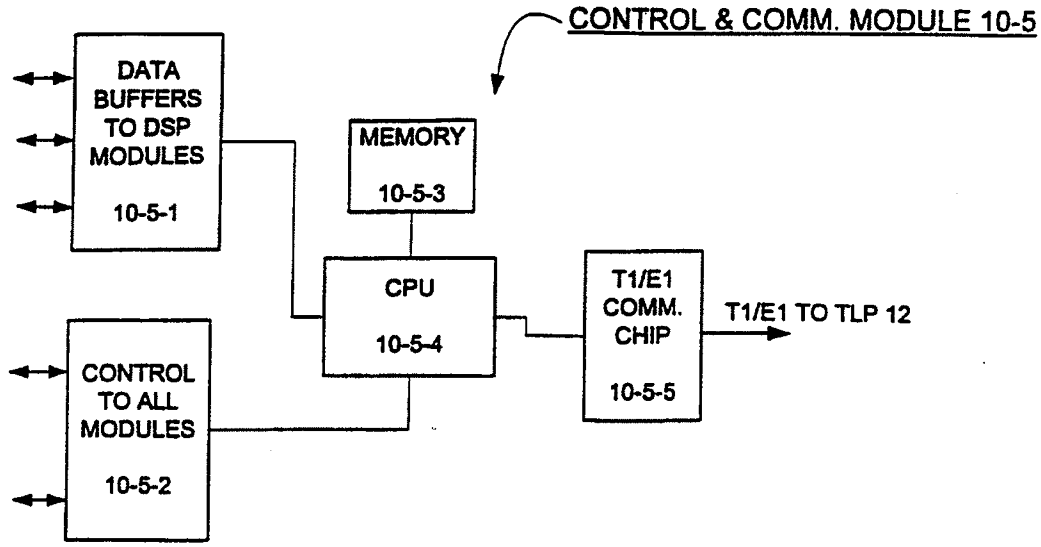


FIGURE 2F

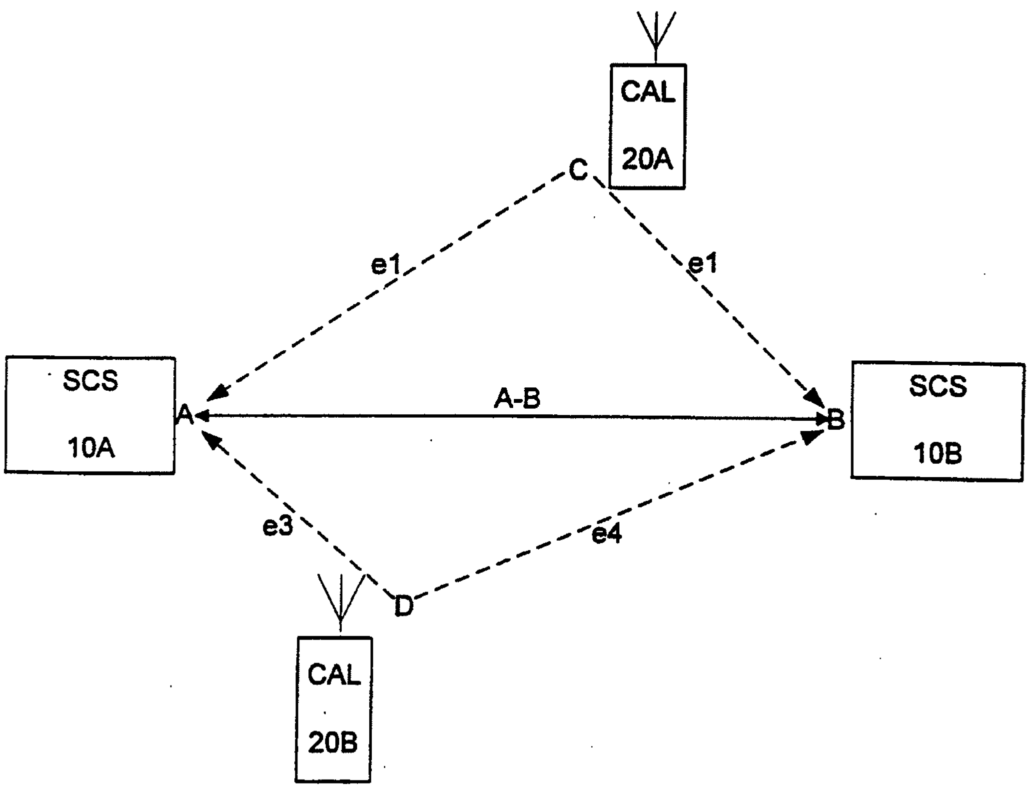


FIGURE 2G

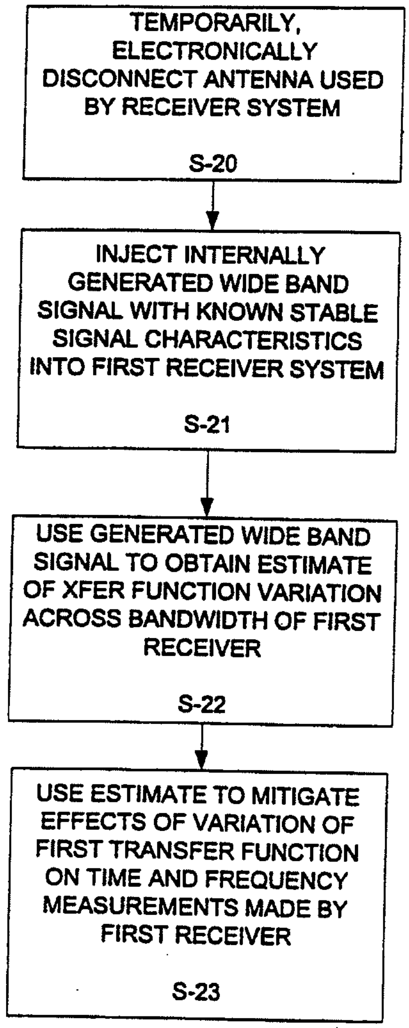

TEMPORARILY, ELECTRONICALLY DISCONNECT ANTENNA USED BY RECEIVER SYSTEM
S-20
INJECT INTERNALLY GENERATED WIDE BAND SIGNAL WITH KNOWN STABLE SIGNAL CHARACTERISTICS INTO FIRST RECEIVER SYSTEM
S-21
USE GENERATED WIDE BAND SIGNAL TO OBTAIN ESTIMATE OF XFER FUNCTION VARIATION ACROSS BANDWIDTH OF FIRST RECEIVER
S-22
USE ESTIMATE TO MITIGATE EFFECTS OF VARIATION OF FIRST TRANSFER FUNCTION ON TIME AND FREQUENCY MEASUREMENTS MADE BY FIRST RECEIVER
S-23

FIGURE 2H

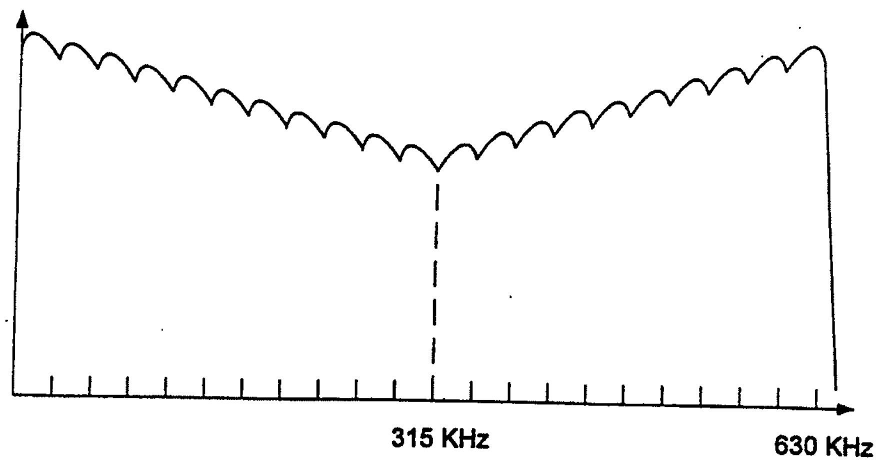


FIGURE 2I

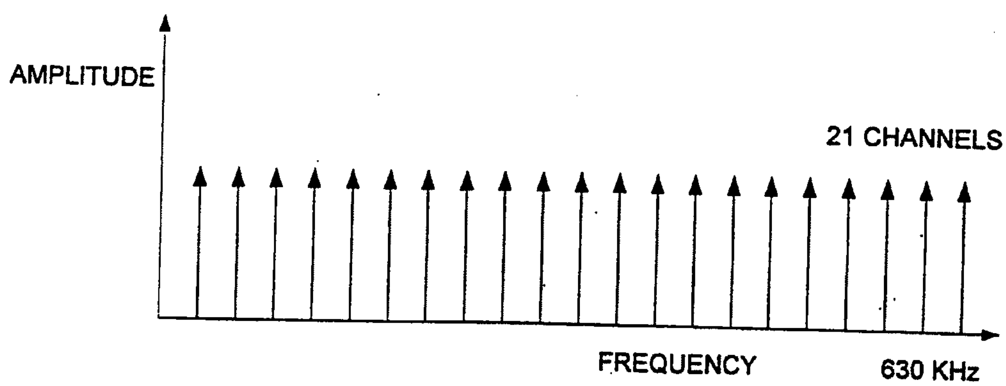


FIGURE 2J

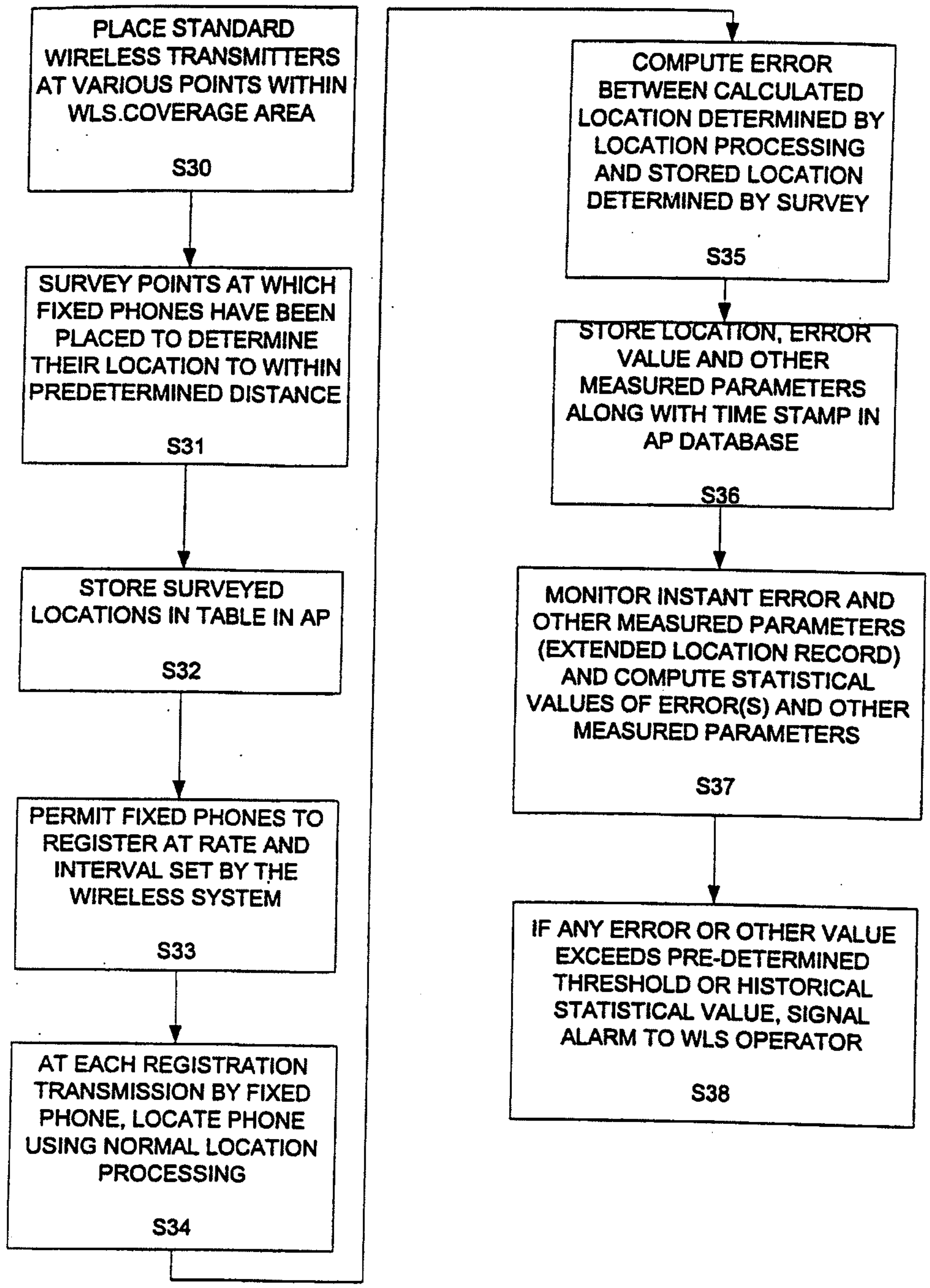

PLACE STANDARD WIRELESS TRANSMITTERS AT VARIOUS POINTS WITHIN WLS COVERAGE AREA
S30
SURVEY POINTS AT WHICH FIXED PHONES HAVE BEEN PLACED TO DETERMINE THEIR LOCATION TO WITHIN PREDETERMINED DISTANCE
S31
STORE SURVEYED LOCATIONS IN TABLE IN AP
S32
PERMIT FIXED PHONES TO REGISTER AT RATE AND INTERVAL SET BY THE WIRELESS SYSTEM
S33
AT EACH REGISTRATION TRANSMISSION BY FIXED PHONE, LOCATE PHONE USING NORMAL LOCATION PROCESSING
S34
COMPUTE ERROR BETWEEN CALCULATED LOCATION DETERMINED BY LOCATION PROCESSING AND STORED LOCATION DETERMINED BY SURVEY
S35
STORE LOCATION, ERROR VALUE AND OTHER MEASURED PARAMETERS ALONG WITH TIME STAMP IN AP DATABASE
S36
MONITOR INSTANT ERROR AND OTHER MEASURED PARAMETERS (EXTENDED LOCATION RECORD) AND COMPUTE STATISTICAL VALUES OF ERROR(S) AND OTHER MEASURED PARAMETERS
S37
IF ANY ERROR OR OTHER VALUE EXCEEDS PRE-DETERMINED THRESHOLD OR HISTORICAL STATISTICAL VALUE, SIGNAL ALARM TO WLS OPERATOR
S38

FIGURE 2K

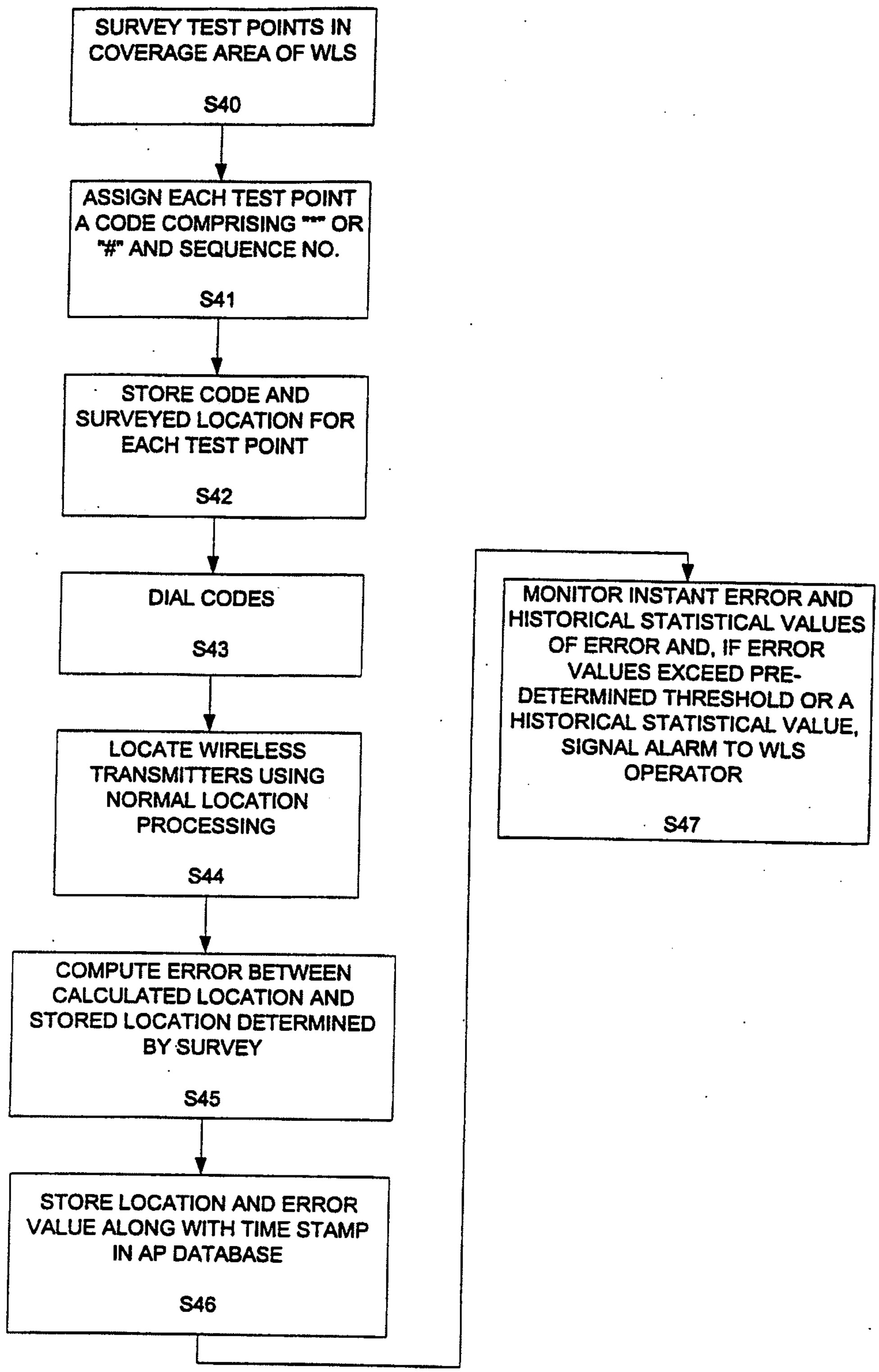

SURVEY TEST POINTS IN COVERAGE AREA OF WLS
S40
ASSIGN EACH TEST POINT A CODE COMPRISING "*" OR "#" AND SEQUENCE NO.
S41
STORE CODE AND SURVEYED LOCATION FOR EACH TEST POINT
S42
DIAL CODES
S43
LOCATE WIRELESS TRANSMITTERS USING NORMAL LOCATION PROCESSING
S44
COMPUTE ERROR BETWEEN CALCULATED LOCATION AND STORED LOCATION DETERMINED BY SURVEY
S45
STORE LOCATION AND ERROR VALUE ALONG WITH TIME STAMP IN AP DATABASE
S46
MONITOR INSTANT ERROR AND HISTORICAL STATISTICAL VALUES OF ERROR AND, IF ERROR VALUES EXCEED PRE-DETERMINED THRESHOLD OR A HISTORICAL STATISTICAL VALUE, SIGNAL ALARM TO WLS OPERATOR
S47

FIGURE 2L

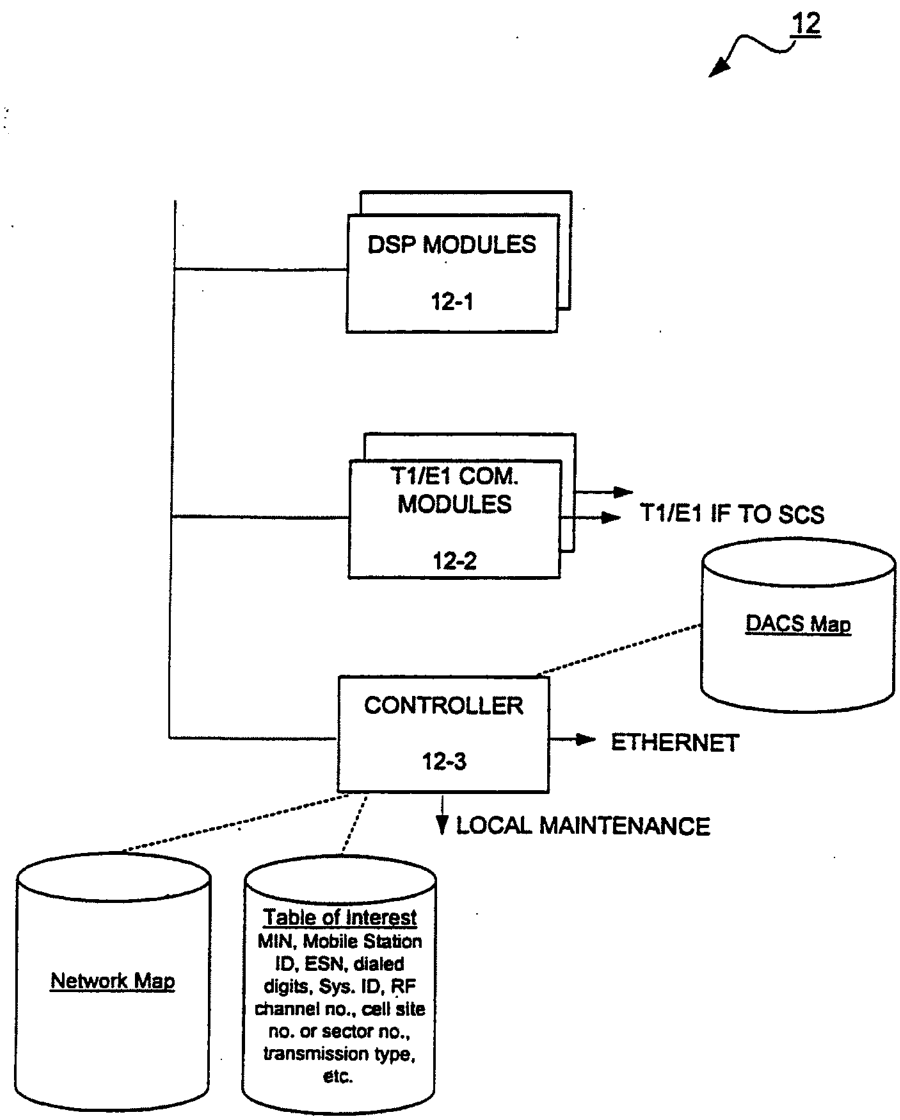
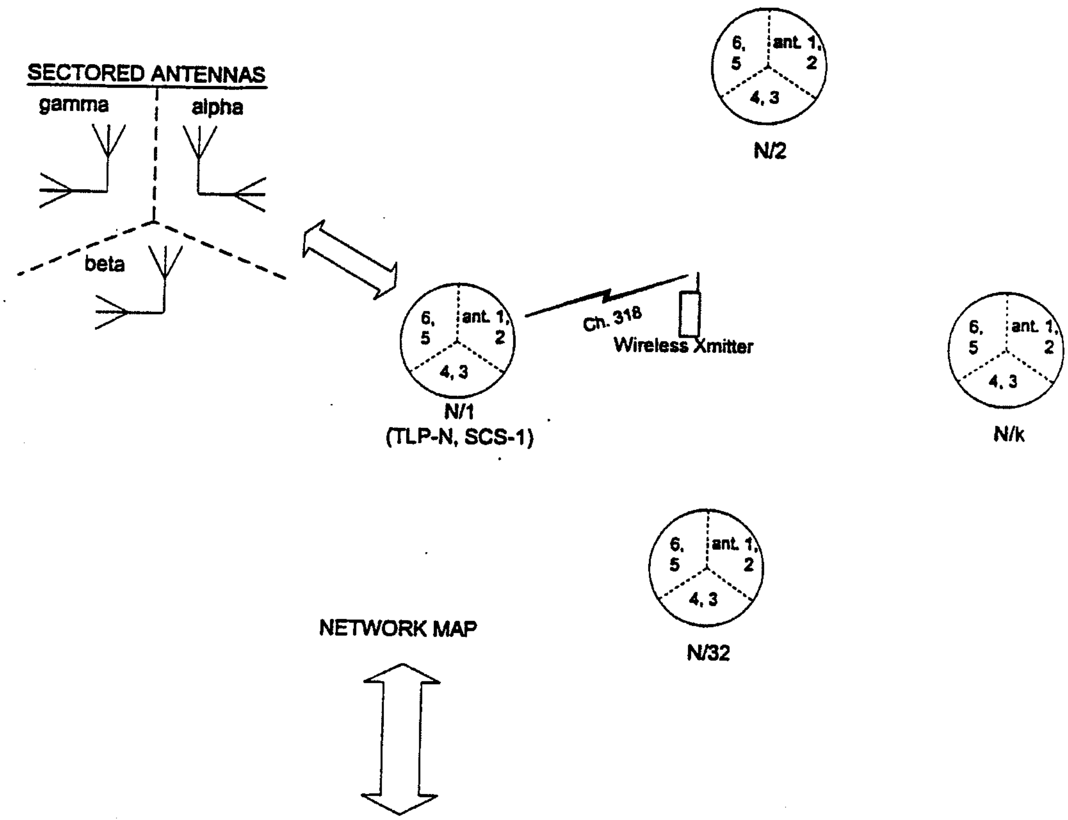

12
DSP MODULES
12-1
T1/E1 COM.
MODULES
12-2
T1/E1 IF TO SCS
DACS Map
CONTROLLER
12-3
ETHERNET
LOCAL MAINTENANCE
Network Map
Table of Interest
MIN, Mobile Station ID, ESN, dialed digits, Sys. ID, RF channel no., cell site no. or sector no., transmission type, etc.

FIGURE 3



DYNAMIC COOPERATION TABLE

		Best Antenna Port
1	TLP 1/SCS 1	1 2 3 4 5 6
	1/2	4 3
	1/3	
	•	
	•	
	•	
	1/k	5 6 3 4
	•	
	•	
	•	
32	N/K	5 6

FIGURE 3A

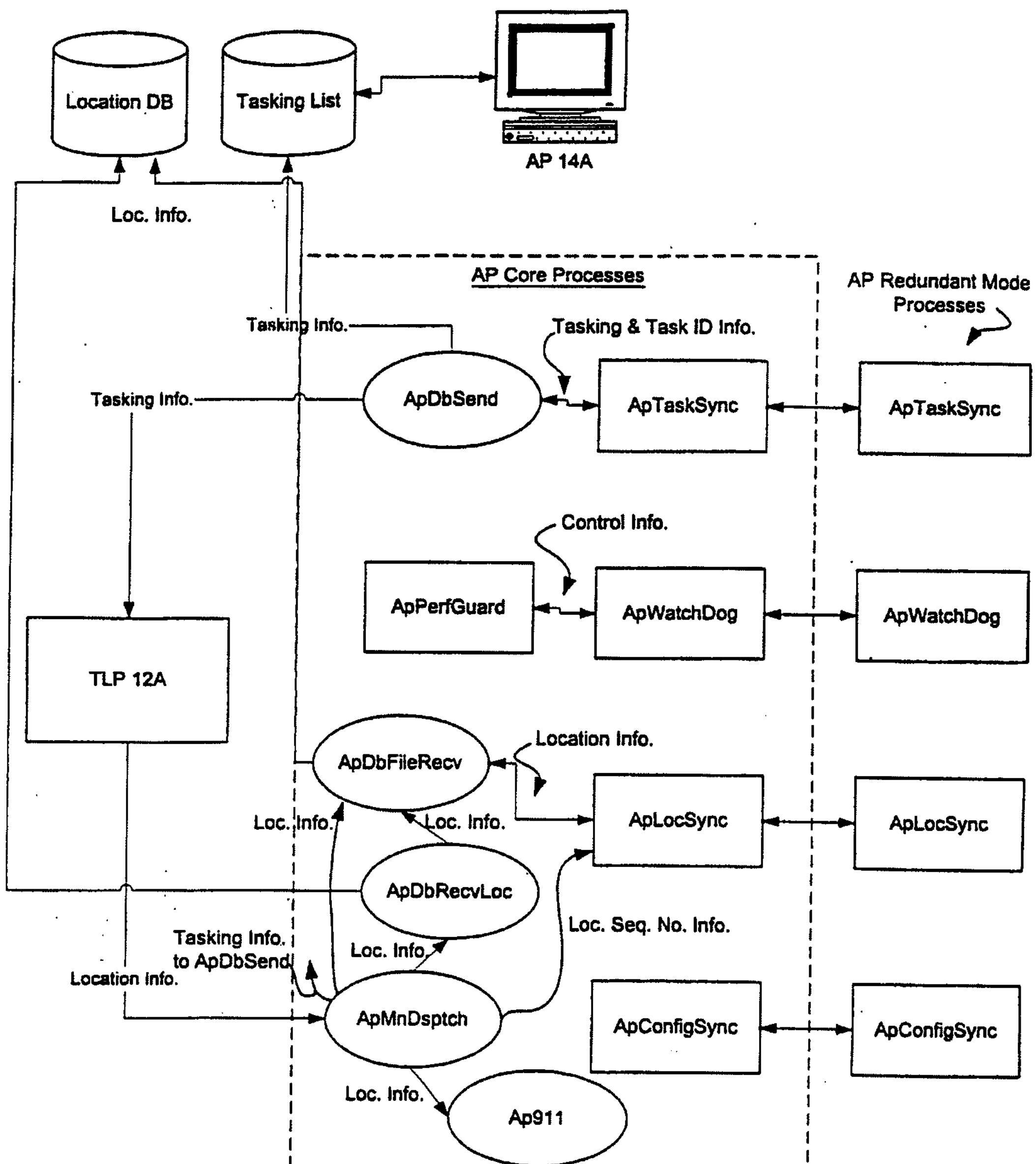

Location DB
Tasking List
AP 14A
Loc. Info.
AP Core Processes
AP Redundant Mode Processes
Tasking Info.
Tasking & Task ID Info.
Tasking Info.
ApDbSend
ApTaskSync
ApTaskSync
Control Info.
ApPerfGuard
ApWatchDog
ApWatchDog
TLP 12A
ApDbFileRecv
Location Info.
ApLocSync
ApLocSync
Loc. Info.
Loc. Info.
ApDbRecvLoc
Loc. Seq. No. Info.
Tasking Info. to ApDbSend
Loc. Info.
Location Info.
ApMnDsptch
ApConfigSync
ApConfigSync
Loc. Info.
Ap911

FIGURE 4

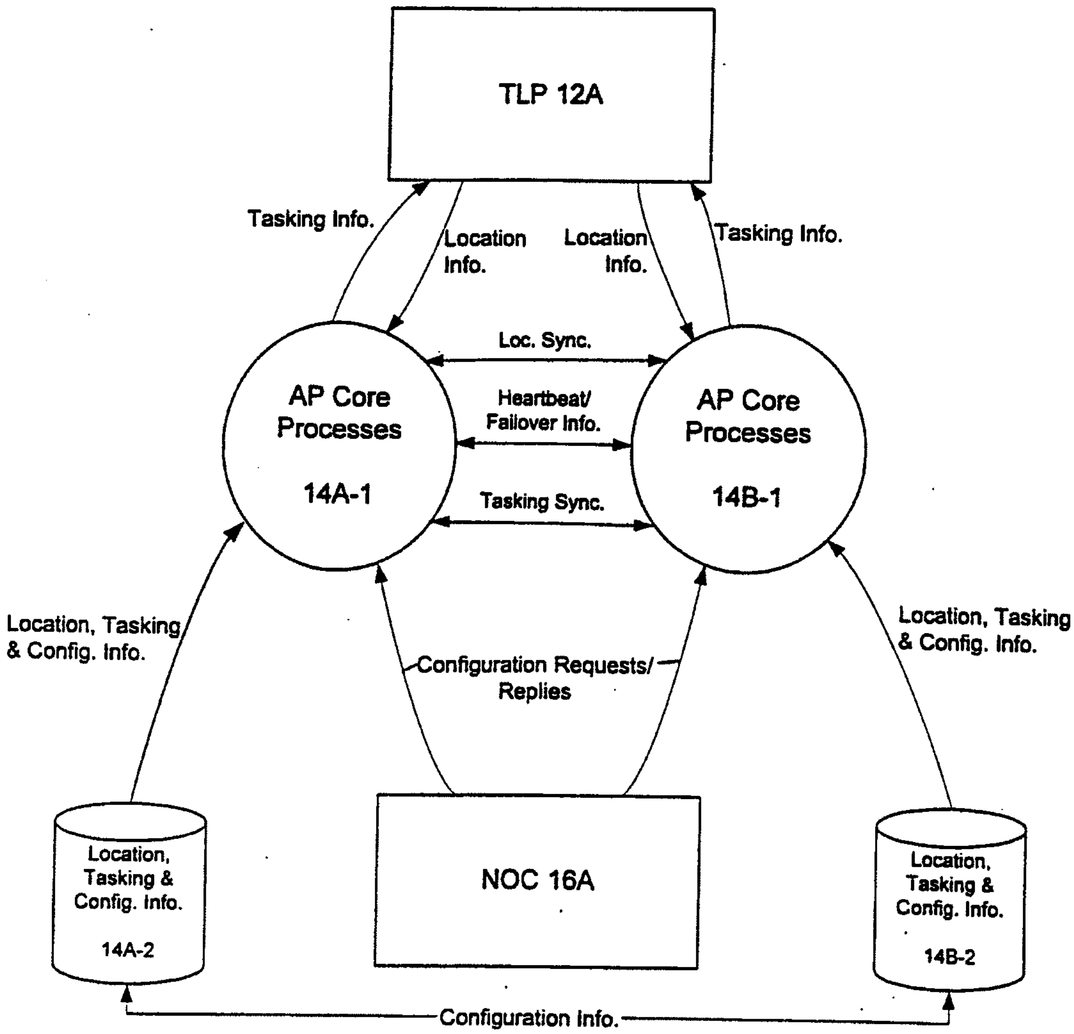

TLP 12A
Tasking Info.
Location Info.
Location Info.
Tasking Info.
Loc. Sync.
AP Core Processes 14A-1
Heartbeat/ Failover Info.
AP Core Processes 14B-1
Tasking Sync.
Location, Tasking & Config. Info.
Configuration Requests/ Replies
Location, Tasking & Config. Info.
Location, Tasking & Config. Info. 14A-2
NOC 16A
Location, Tasking & Config. Info. 14B-2
Configuration Info.

FIGURE 4A

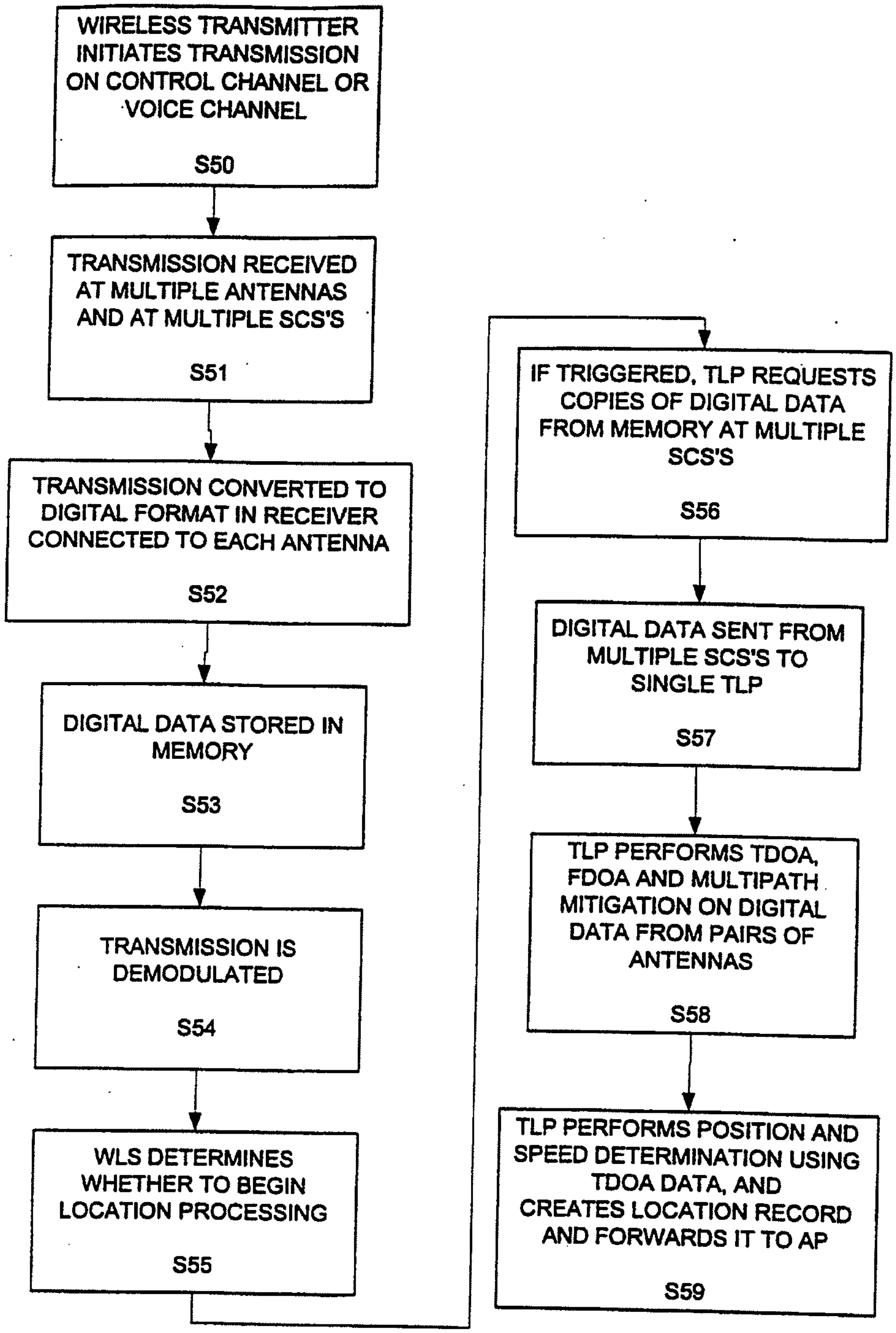
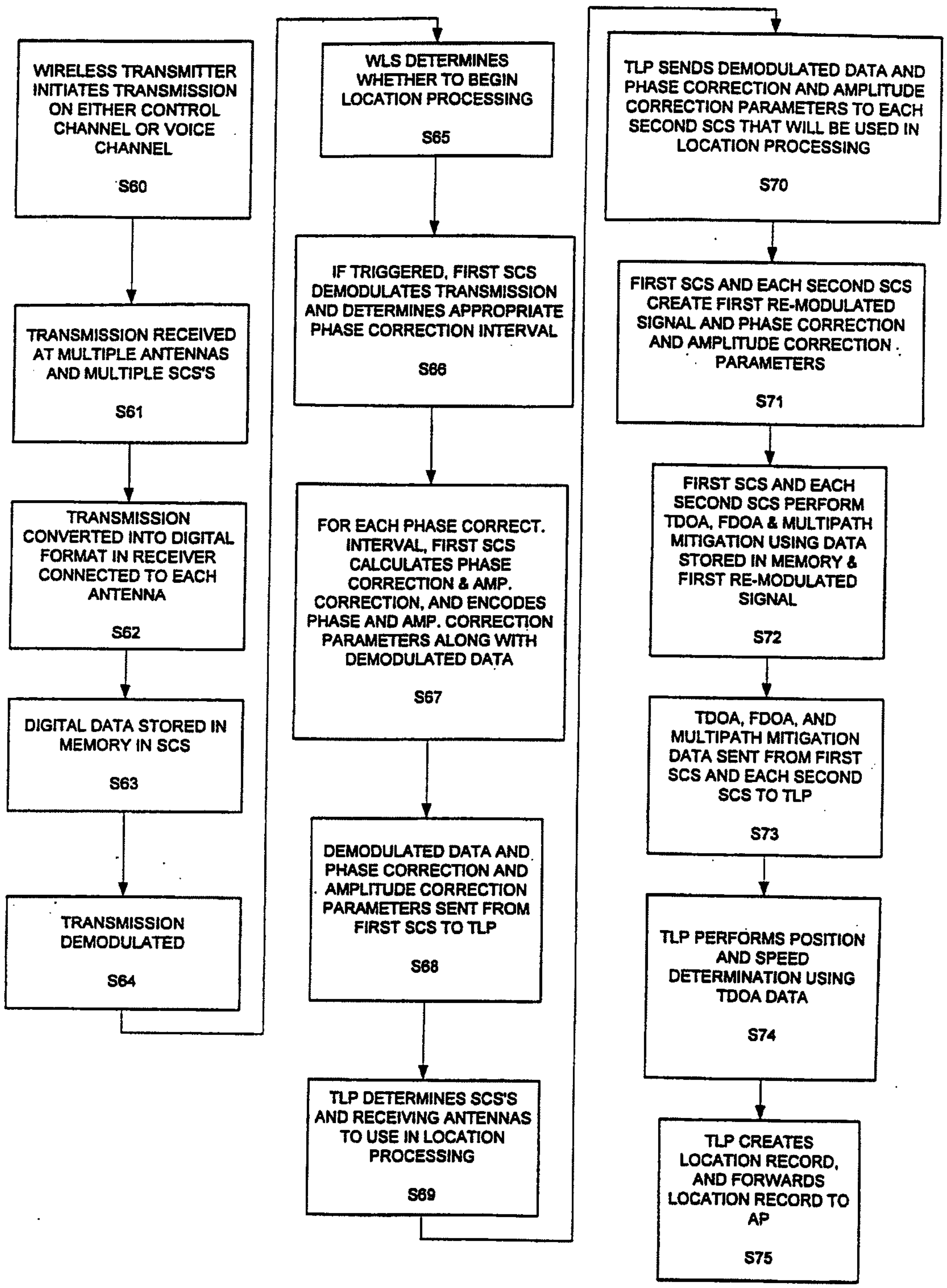

WIRELESS TRANSMITTER INITIATES TRANSMISSION ON CONTROL CHANNEL OR VOICE CHANNEL
S50
TRANSMISSION RECEIVED AT MULTIPLE ANTENNAS AND AT MULTIPLE SCS'S
S51
TRANSMISSION CONVERTED TO DIGITAL FORMAT IN RECEIVER CONNECTED TO EACH ANTENNA
S52
DIGITAL DATA STORED IN MEMORY
S53
TRANSMISSION IS DEMODULATED
S54
WLS DETERMINES WHETHER TO BEGIN LOCATION PROCESSING
S55
IF TRIGGERED, TLP REQUESTS COPIES OF DIGITAL DATA FROM MEMORY AT MULTIPLE SCS'S
S56
DIGITAL DATA SENT FROM MULTIPLE SCS'S TO SINGLE TLP
S57
TLP PERFORMS TDOA, FDOA AND MULTIPATH MITIGATION ON DIGITAL DATA FROM PAIRS OF ANTENNAS
S58
TLP PERFORMS POSITION AND SPEED DETERMINATION USING TDOA DATA, AND CREATES LOCATION RECORD AND FORWARDS IT TO AP
S59

FIGURE 5



WIRELESS TRANSMITTER INITIATES TRANSMISSION ON EITHER CONTROL CHANNEL OR VOICE CHANNEL S60
TRANSMISSION RECEIVED AT MULTIPLE ANTENNAS AND MULTIPLE SCS'S S61
TRANSMISSION CONVERTED INTO DIGITAL FORMAT IN RECEIVER CONNECTED TO EACH ANTENNA S62
DIGITAL DATA STORED IN MEMORY IN SCS S63
TRANSMISSION DEMODULATED S64
WLS DETERMINES WHETHER TO BEGIN LOCATION PROCESSING S65
IF TRIGGERED, FIRST SCS DEMODULATES TRANSMISSION AND DETERMINES APPROPRIATE PHASE CORRECTION INTERVAL S66
FOR EACH PHASE CORRECT. INTERVAL, FIRST SCS CALCULATES PHASE CORRECTION & AMP. CORRECTION, AND ENCODES PHASE AND AMP. CORRECTION PARAMETERS ALONG WITH DEMODULATED DATA S67
DEMODULATED DATA AND PHASE CORRECTION AND AMPLITUDE CORRECTION PARAMETERS SENT FROM FIRST SCS TO TLP S68
TLP DETERMINES SCS'S AND RECEIVING ANTENNAS TO USE IN LOCATION PROCESSING S69
TLP SENDS DEMODULATED DATA AND PHASE CORRECTION AND AMPLITUDE CORRECTION PARAMETERS TO EACH SECOND SCS THAT WILL BE USED IN LOCATION PROCESSING S70
FIRST SCS AND EACH SECOND SCS CREATE FIRST RE-MODULATED SIGNAL AND PHASE CORRECTION AND AMPLITUDE CORRECTION PARAMETERS S71
FIRST SCS AND EACH SECOND SCS PERFORM TDOA, FDOA & MULTIPATH MITIGATION USING DATA STORED IN MEMORY & FIRST RE-MODULATED SIGNAL S72
TDOA, FDOA, AND MULTIPATH MITIGATION DATA SENT FROM FIRST SCS AND EACH SECOND SCS TO TLP S73
TLP PERFORMS POSITION AND SPEED DETERMINATION USING TDOA DATA S74
TLP CREATES LOCATION RECORD, AND FORWARDS LOCATION RECORD TO AP S75

FIGURE 6

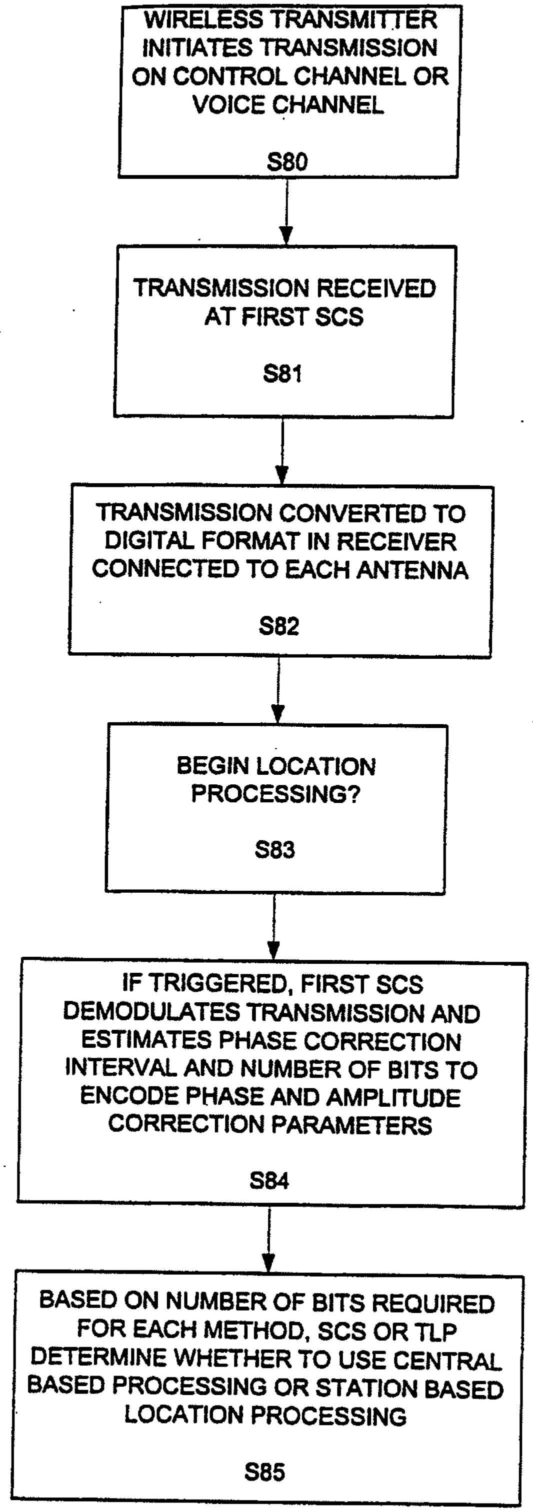

WIRELESS TRANSMITTER INITIATES TRANSMISSION ON CONTROL CHANNEL OR VOICE CHANNEL
S80
TRANSMISSION RECEIVED AT FIRST SCS
S81
TRANSMISSION CONVERTED TO DIGITAL FORMAT IN RECEIVER CONNECTED TO EACH ANTENNA
S82
BEGIN LOCATION PROCESSING?
S83
IF TRIGGERED, FIRST SCS DEMODULATES TRANSMISSION AND ESTIMATES PHASE CORRECTION INTERVAL AND NUMBER OF BITS TO ENCODE PHASE AND AMPLITUDE CORRECTION PARAMETERS
S84
BASED ON NUMBER OF BITS REQUIRED FOR EACH METHOD, SCS OR TLP DETERMINE WHETHER TO USE CENTRAL BASED PROCESSING OR STATION BASED LOCATION PROCESSING
S85

FIGURE 7

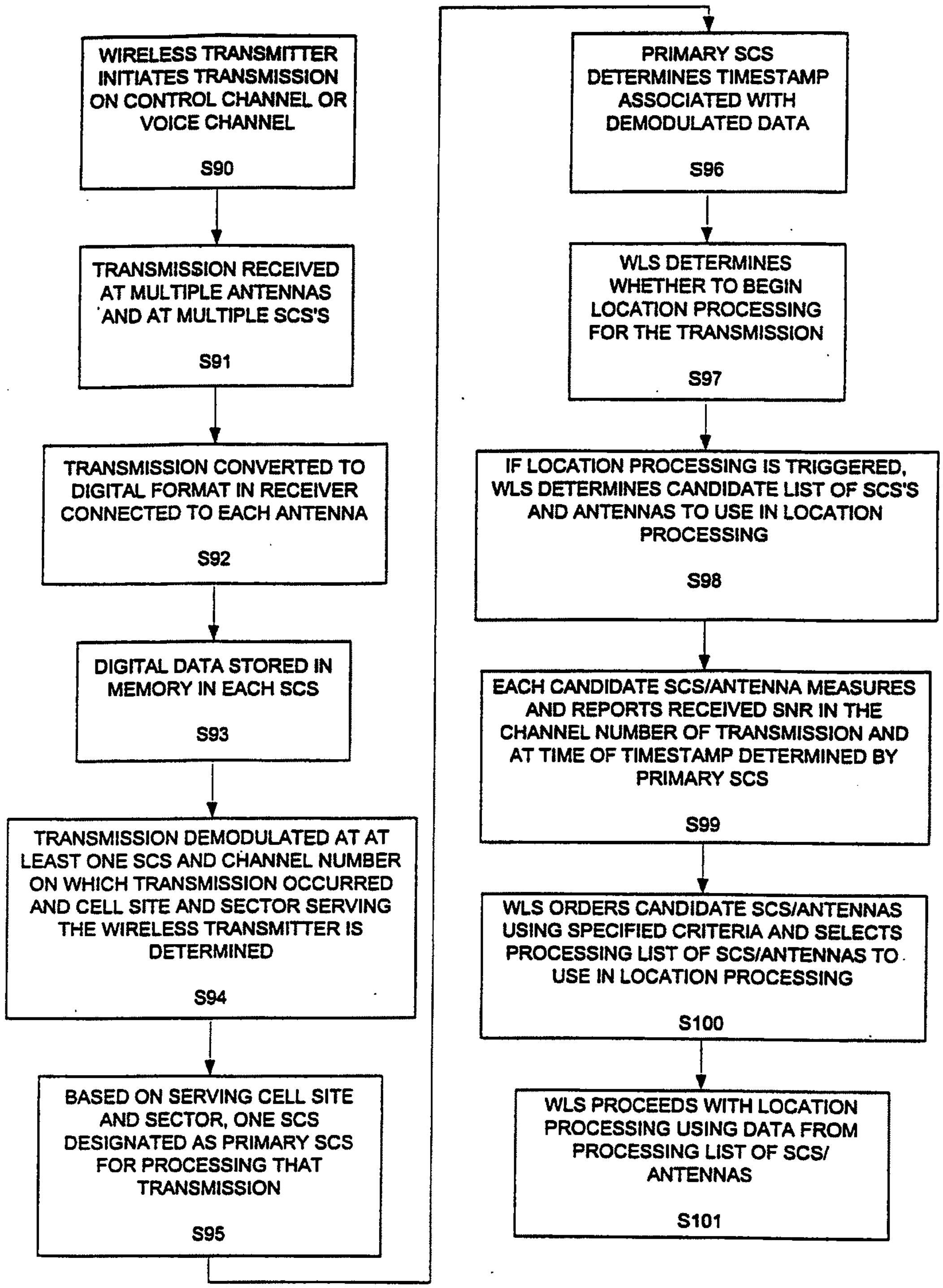

WIRELESS TRANSMITTER INITIATES TRANSMISSION ON CONTROL CHANNEL OR VOICE CHANNEL
S90
TRANSMISSION RECEIVED AT MULTIPLE ANTENNAS AND AT MULTIPLE SCS'S
S91
TRANSMISSION CONVERTED TO DIGITAL FORMAT IN RECEIVER CONNECTED TO EACH ANTENNA
S92
DIGITAL DATA STORED IN MEMORY IN EACH SCS
S93
TRANSMISSION DEMODULATED AT AT LEAST ONE SCS AND CHANNEL NUMBER ON WHICH TRANSMISSION OCCURRED AND CELL SITE AND SECTOR SERVING THE WIRELESS TRANSMITTER IS DETERMINED
S94
BASED ON SERVING CELL SITE AND SECTOR, ONE SCS DESIGNATED AS PRIMARY SCS FOR PROCESSING THAT TRANSMISSION
S95
PRIMARY SCS DETERMINES TIMESTAMP ASSOCIATED WITH DEMODULATED DATA
S96
WLS DETERMINES WHETHER TO BEGIN LOCATION PROCESSING FOR THE TRANSMISSION
S97
IF LOCATION PROCESSING IS TRIGGERED, WLS DETERMINES CANDIDATE LIST OF SCS'S AND ANTENNAS TO USE IN LOCATION PROCESSING
S98
EACH CANDIDATE SCS/ANTENNA MEASURES AND REPORTS RECEIVED SNR IN THE CHANNEL NUMBER OF TRANSMISSION AND AT TIME OF TIMESTAMP DETERMINED BY PRIMARY SCS
S99
WLS ORDERS CANDIDATE SCS/ANTENNAS USING SPECIFIED CRITERIA AND SELECTS PROCESSING LIST OF SCS/ANTENNAS TO USE IN LOCATION PROCESSING
S100
WLS PROCEEDS WITH LOCATION PROCESSING USING DATA FROM PROCESSING LIST OF SCS/ ANTENNAS
S101

FIGURE 8

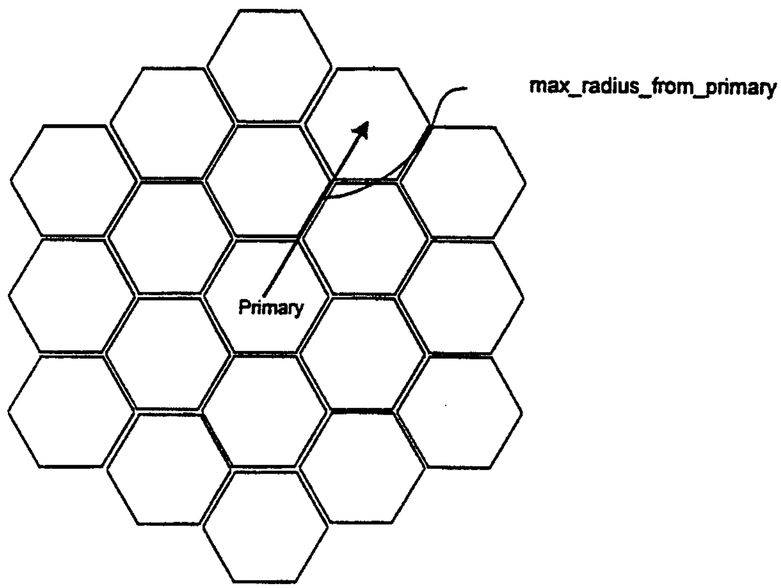


FIGURE 9

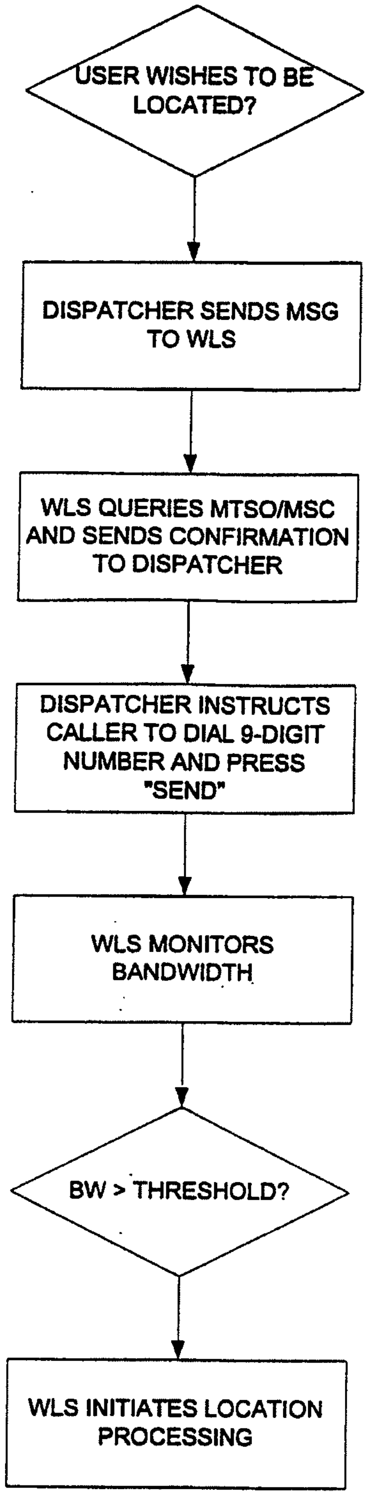


FIGURE 10A

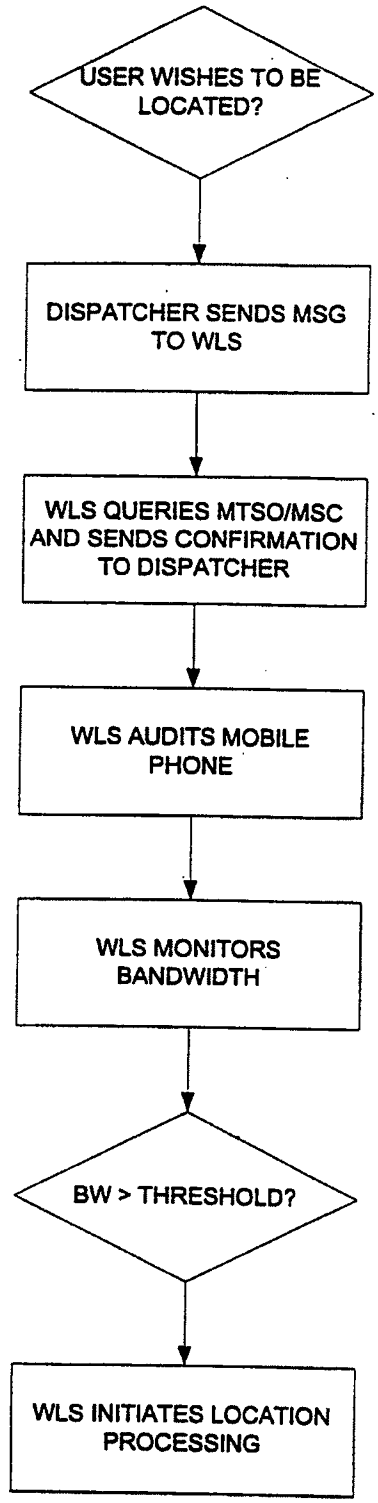


FIGURE 10B

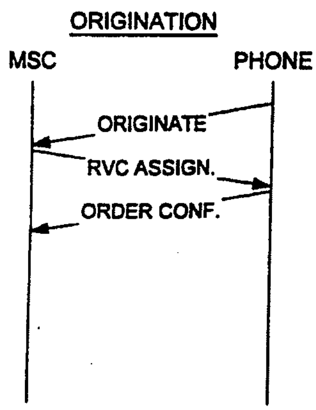


FIGURE 11A

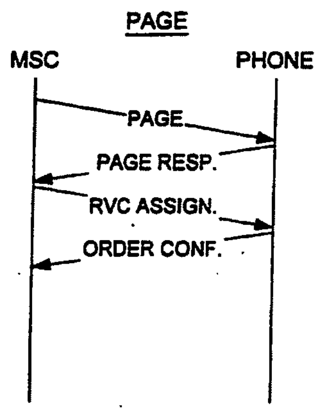


FIGURE 11B

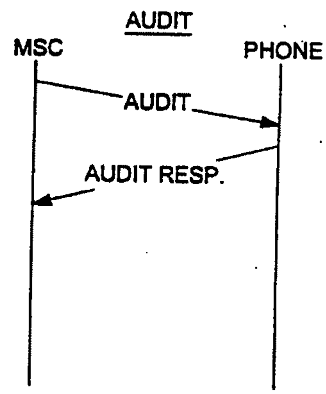


FIGURE 11C

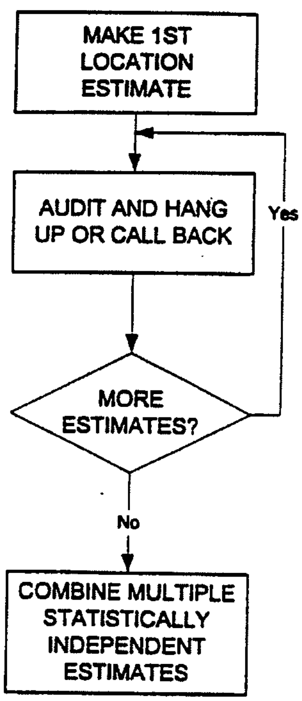


FIGURE 11D

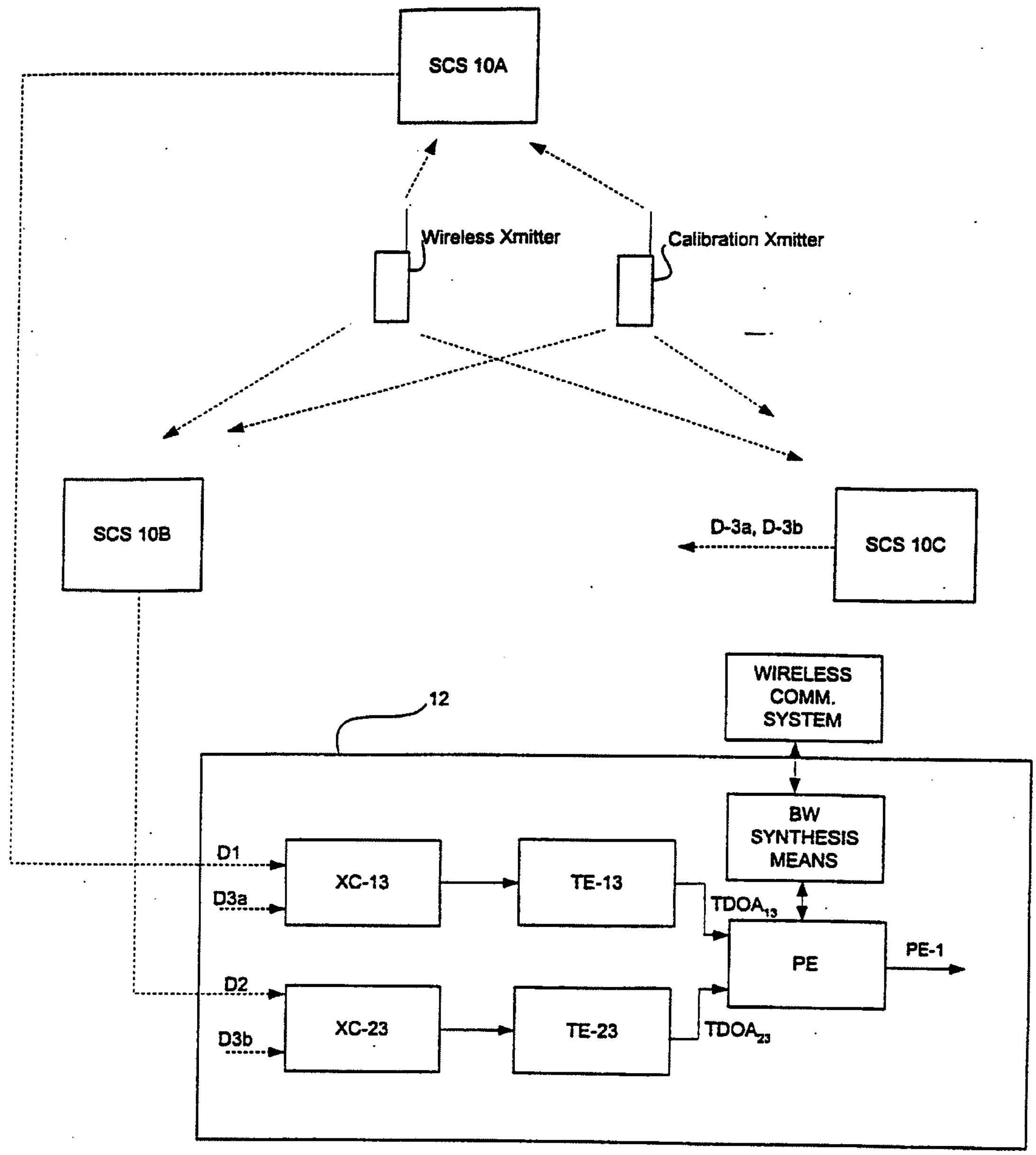

SCS 10A
Wireless Xmitter
Calibration Xmitter
SCS 10B
D-3a, D-3b
SCS 10C
12
WIRELESS COMM. SYSTEM
BW SYNTHESIS MEANS
D1
D3a
XC-13
TE-13
TDOA13
PE
PE-1
D2
XC-23
TE-23
TDOA23
D3b

FIGURE 12A

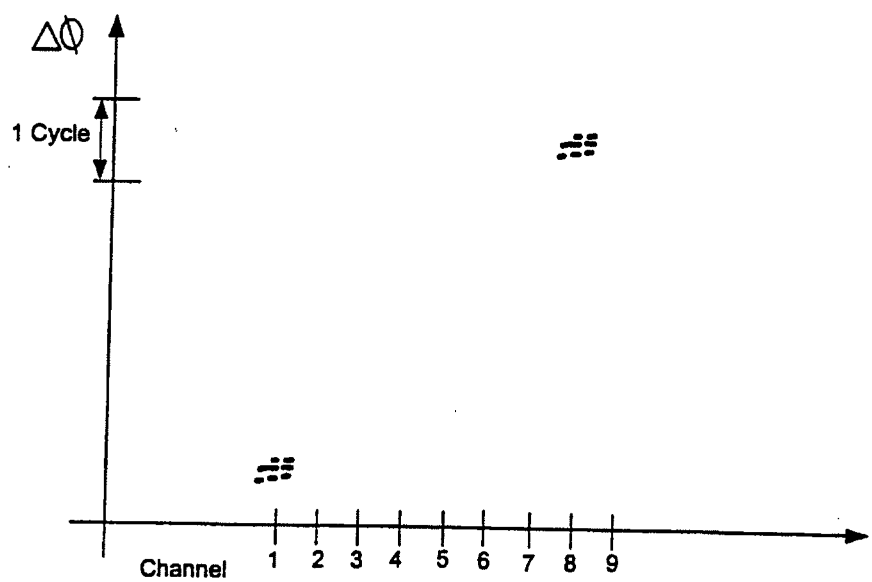


FIGURE 12B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/29507

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) :G01S 3/02; HO4B 7/185
US CL :342/457, 357.01
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 342/450, 457,357.01

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

None

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

bandwidth, threshold, rvc, reverse voice

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 5,402,347 A (MCBURNEY et al) 28 March 1995 (28.3.95); Fig. 1	30 36-37
X	US 3,921,076 A (CURRIE) 18 November 1975 (18.11.75); Fig. 1, col 3, line 63 - col 4, line 55	30

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
07 APRIL 2000	16 MAY 2000

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231
Facsimile No. (703) 305-3230

Authorized officer
DAO L. PHAN
Telephone No. (703) 306-4167